AD-A164 384 PROCEEDINGS OF THE WIRE AND CABLE SYMPOSIUM (34TH) HELD 5/5
AT CHERRY HILL NEW JERSEY ON 19-21 NOVEMBER 1985(U)
ARMY COMMUNICATIONS-ELECTRONICS COMMAND FORT MONMOUTH
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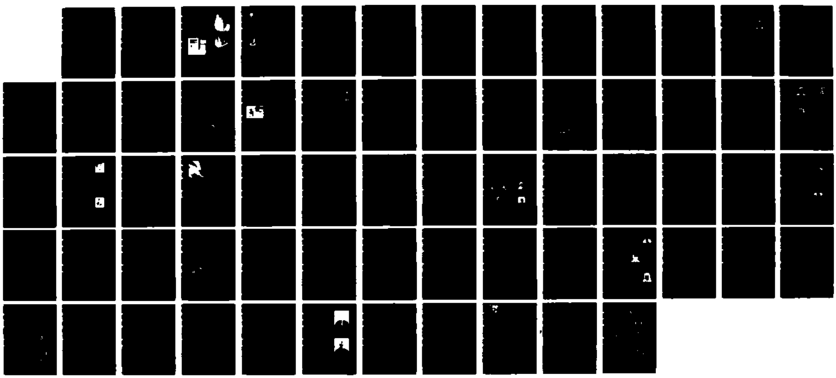
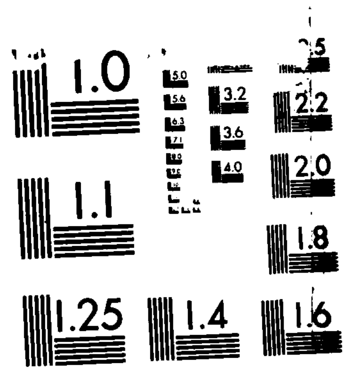




MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

6. SECURITY

It can be seen from Figures 1 to 5 that a customer can, if he so wishes, be provided with two independent fibre connections to different Distribution Nodes. This kind of connection will ensure that the customer remains in service should there be a failure of the primary cable at any point between that particular customer's PFP and one of the Distribution Nodes. Equally, service interruption due to a catastrophic failure at a Distribution Node can be circumvented by simply re-splicing affected customers into adjacent Distribution Nodes.

There is still a risk, however, that the secondary cable carrying both links is damaged, although this is quite minimal since the secondary link will be typically less than 100 m. However, the risk can be removed by the addition of a secondary link from a different primary cable (See Fig.6). This back-up link can be arranged to enter the customer's premises by a different route for the ultimate protection.

The facility to offer a diverse route is beneficial in recovering from cable breakdown and during maintenance operations. Customers without a diverse route can be temporarily supplied with one in such instances.

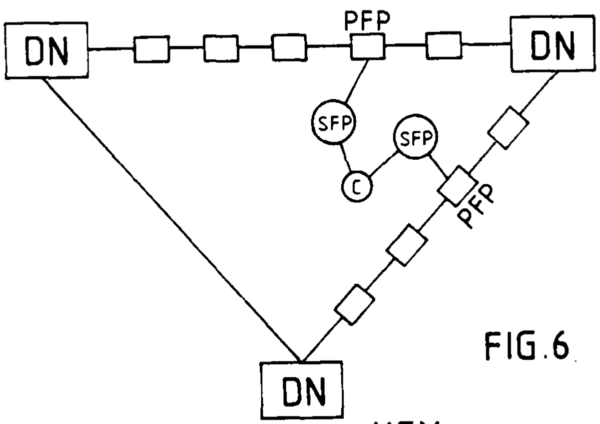


FIG.6

KEY
DN-Distribution Node
C-Customer
PFP-Primary Flexibility Point
SFP-Secondary Flexibility Point

In the City of London, the hydraulic pipe network was installed many years ago beneath the carriageway and, as a result, the Primary Distribution Network including the manholes containing the PFPs is installed in the carriageway. Although this poses some problems during installation due to the presence of heavy vehicular traffic, it is thought that there will be some additional security benefit in that the primary cables and PFPs will be physically divorced from all the congestion and inevitable hazards that exist in the footway.

For this reason, it is expected that the Primary Network of future installations in major UK centres will also be in the carriageway.

In terms of mechanical protection, the LHP pipes provide an ideal duct route since they consist of steel and cast-iron sections with wall thicknesses of upto 1½ inches.

7. NETWORK EXPANSION

The network can be expanded in a number of ways to cope with the various demands placed on it in the future.

i) Careful choice of fibre performance will ensure that the long term needs of most business customers will be satisfied by simply upgrading the terminal equipment.

ii) Increased penetration of customers connected will be accommodated by installing further primary cables and PFPs within the initially constructed manhole and duct network. Sub-ducting techniques are employed to facilitate additional cable installation, and care is taken at the outset to ensure that all carriageway chambers are large enough to accommodate 2-3 PFPs.

iii) Increased traffic levels will dictate the need for more equipment space at each Distribution Node. At that time, new Distribution Nodes will be introduced by intercepting the Primary Distribution Network at any convenient PFP.

8. INSTALLATION

Prior to actual installation, a small model of the proposed network was constructed, including full size versions of the individual components used -i.e. Primary and Secondary Flexibility Points, Joint Chambers etc. (see photographs at the end of this paper).

This exercise provided invaluable data such as:

i) Quantity of cable and fibre to be stored at each Primary and Secondary Flexibility Point location.

ii) Manpower required to fit a PFP to a 160-fibre cable to assist in Manpower planning.

The actual installation project entailed four discrete activities -

i) Ductwork civil engineering - i.e. LHP refurbishment work.

ii) Subduct installation.

iii) Primary Distribution cabling - this activity was extended to include some secondary cabling required to connect the first few customers.

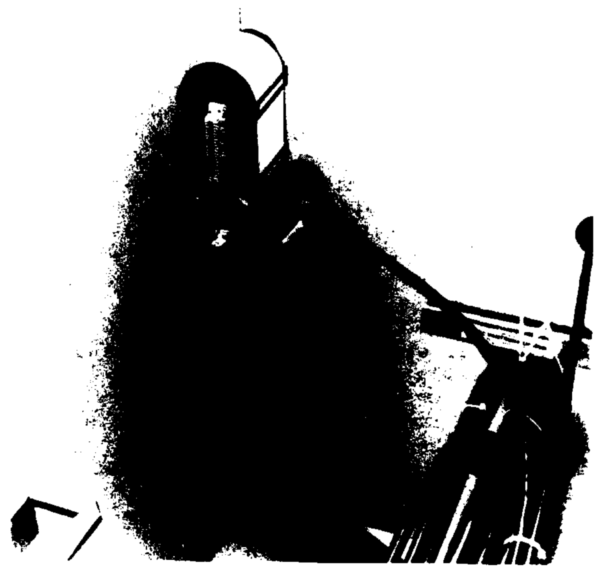
iv) Cable Distribution Nodes established.

Primary Flexibility Points were housed in manholes which were built in place of the 'T' joints and valves that formed part of the hydraulic pipe network. This pipe network was found to be very comprehensive with joints and valves at almost all major road junctions and many smaller ones.

9. CONCLUSION

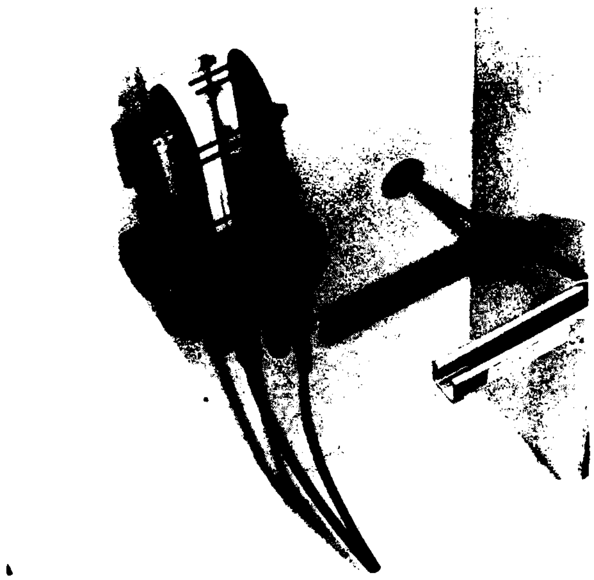
Currently available optical cables and devices have made it possible to design a Local Wideband Network for public use, which makes cost-effective use of the minimal space available in the City of London and, indeed, any other Central Business District.

By providing a hybrid 'Ring-main/ Taper' distribution network, various levels of diversity can be made available to ensure the continuity of service demanded by todays business users.



Primary Flexibility Point in a Jointing Chamber

Cable Termination Rack for Two 160-Fibre Cables



Secondary Flexibility Point with one Customer Drop Cable fitted

ACKNOWLEDGEMENT

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COST EFFECTIVE OPTICAL SYSTEMS FOR UK JUNCTION NETWORK

C H ROBBINS

BRITISH TELECOM, LONDON, UK

SUMMARY

In April 1983 British Telecom confirmed plans to accelerate their overall network modernisation with the target date for digital replacement of the associated transmission links from local exchanges, BT's junction network, brought forward to 1995. The economics of an optical solution in this environment where low capacity routes of limited length proliferate have always been unfavourable and a constraint on their use. The paper outlines how BT approached UK Industry with a definition of the prospective optical fibre and equipment market which could be enjoyed if costs could be significantly reduced. This approach has now precipitated volume production of cost effective cable and equipment operating at 8Mbit/s over multimode fibre. However, the price trends in optical fibre production have changed dramatically over the last two years and the paper concludes with a consideration of the factors related to the economic exploitation of single mode fibre in this part of the Network.

INTRODUCTION

British Telecom's Junction Network provides the transmission links between local exchanges and more importantly, from each local exchange to its parent higher order exchange, nominally the Group Switching Centre (GSC). Traffic is carried over 1.1M circuits currently amalgamated on 63000 traffic routes. In simple terms the Network is configured as individual star networks radiating from each of the 350 GSC sites. In contrast there are some 6500 local exchanges and junction requirements are directly dependent on the distribution of these local exchange types in terms of numbers, switching capacity and distance from the parent GSC site. Over half the traffic originates from a relatively small number (1500) of large local exchanges, the remaining traffic being thinly distributed over the other 5000 small local units. It is therefore not surprising that 'low capacity' transmission systems represent the largest proportion in any potential junction, optical fibre market.

The adoption of an Integrated Digital Network (IDN) strategy 4 years ago heralded the start of a major digital transmission planning and provision programme. The Junction Network (JN) objective was to achieve 100% digitalisation by the year 2000. A task of this magnitude demands a readily available supply of cost effective digital transmission systems in large production volumes. Historically optical fibre systems, particularly at 2 and 8Mbit/s, had failed to satisfy these basic criteria. The major constaint being the high cost of both fibre, cable sheathing and equipment.

POTENTIAL OPTICAL MARKET

In April 1983 BT confirm[illegible]ns to accelerate the modernisation progr[illegible]me based on an increased availability of digital exchange production capacity. The target date for completing Junction digitalisation was brought forward 5 years but more significantly the bulk of work had to be done by 1990. With procurement lead times of typically 2 years this change of strategy highlighted the need for an immediate break-through on optical costs. Any delay in introducing a cost effective "low bit rate" system would clearly reduce the potential market size and leave the network with a higher proportion of conventional systems.

It was therefore essential to act quickly and secure support from UK Industry to ensure volume production in reasonable timescales. To encourage such support it was necessary to define:

i) The potential optical cable and equipment market.

ii) Target prices for the primary elements of the prospective optical systems.

In a network modernisation environment Junction transmission requirements are directly dependent on the distribution of local exchanges by:

i) exchange type

ii) numbers of exchanges in each category

iii) average connection size

iv) distance from the parent exchange

v) digitalisation period.

These parameters are shown in Table 1 together with the typical optical system bit rate appropriate for links in each category.

DISTRIBUTION OF LOCAL EXCHANGES

	TXS LARGE	TX E4/ 4A	TXK 1/3	TXE2	TXS SMALL	TXS VERY SMALL
AVERAGE CX SIZE	12,000	13,500	8000	2000	1000	500
NUMBER OF UNITS	870	330	530	1500	1000	1800
DISTANCE FROM PARENT KM	7	6	7	13	11	17
LINKS DIGITAL BY	1990	1990	1990	1995	1995	1995
TYPICAL OFS (Mbit/s)	34/8	34/8	34/8	8/2	2	2

TABLE 1

A simple SBC based network model provided the framework to calculate the longer term requirements for digital line plant, expenditure and manpower. To derive the potential market for OFS the size of the various transmission links were bracketed and related to specific optical system bit rates. The final output provided a theoretical guide to the total potential fibre and equipment market over the modernisation period. The study programme ignored existing digital plant so it is important to stress that the practical market size would be smaller. The results of this study are shown in Tables 2 and 3 against the assumptions that total network demand would be met by:-

a) Full availability of 2, 8 and 34Mbit/s OFS

b) Only 8Mbit/s OFS

c) Only 8 and 34Mbit/s OFS.

FIBRE MARKET

[F/km (000's/ANNUM)]

STUDY \ SYSTEM (Mbit/s)	2	8	34	TOTAL
2-8-34 Mbit/s	75	10	5	90
8 Mbit/s only		50		50
8-34 Mbit/s only		33	5	38

TABLE 2

EQUIPMENT MARKET

(Equipment ends/annum)

STUDY \ SYSTEM Mbit/s	2	8	34	TOTAL
2-8-34 Mbit/s	2000	500	850	3350
8 Mbit/s only		2500		2500
8-34 Mbit/s only		1500	850	2350

TABLE 3

We can see that the fibre market, and to a lesser extent the "equipment end" market are strongly influenced by the availability of a cost effective 2Mbit/s optical system. This simply reflects the proliferation of small routes in the Junction Network. It is equally obvious that there is only a restricted market for 34Mbit/s systems.

If any sizeable optical penetration is to be achieved industry must produce a cost effective 8 and/or 2Mbit/s system. The ultimate choice would largely be dictated by the prevailing system costs.

SYSTEM ECONOMICS

It will be obvious by now that cost had been the restraining influence on optical penetration in the Junction Network. In the past we have specified the system requirements; placed tenders with Industry and then adjudicated on both technical and cost grounds. Thus costs have been obtained as a by-product of the system requirements.

Because of the necessity to make a rapid break-through in this difficult area it was decided to start by "specifying" the required costs for an optical system that would be competitive with the conventional transverse screen cable based PCM system equivalent. The conclusions derived from an iterative cost analysis to meet this requirement are captured in Table 4. The simple message was that the costs of both cable and equipment had to be half the prevailing proprietary system level if either 8 or 34Mbit/s systems were to be totally cost effective.

TARGET PRICES FOR COST EFFECTIVE SYSTEMS
[DIRECT STORES COST (£)]

	(8F) CABLE/km			L.T.E.			2/8 MUX	2/8 MUX
	34	8	2	34	8	2		
POLS 3	3500	2000	—	3400	2000	—	2400	2700
REQUIRED	1500	1400	1000	1700	1000	500	1200	1350

TABLE 4

The next step was to predict from the most up to date information what the real system costs might be in say 1985 and then compare these with the required target costs.

Fibres

The general pattern of multimode fibre prices at that time can be seen in Fig 1, the information being taken from Cornings 81 catalogue.

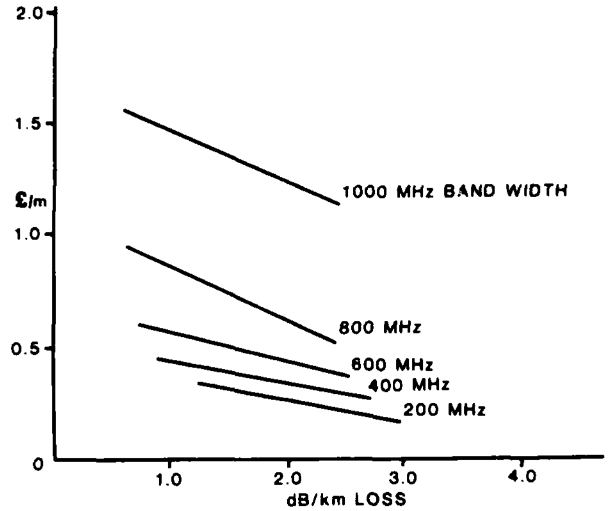


FIGURE 1 - DISTRIBUTION OF FIBRE COSTS (Corning June 1981)

An examination of the market place indicated two important trends.

i) Prices were generally reducing

ii) Those reductions were progressively more marked as fibre quality increased.

These factors have the effect of "closing-up" the lines in Fig 1 such that the price differential in the 1dB/400MHz and 600 MHz would be small.

For the purpose of the study it was predicted that 10 pence/metre provided a challenging but realistic target for 1985 fibre prices assuming significant production volume.

Cable Construction

Looking at 1985 when fibre prices should be further reduced it was clear that the cable sheathing element could grossly predominate.

Although there are a myriad of different cable construction designs they were simply categorised according to basic design philosophy. The likely costs for three basic options are given below.

TYPE	Central Strength member	"high strength" hollow tube	Simple hollow tube
Cost/Km			
£	1500	750	300

It was assumed that option 2 represented a realistic figure for 1985 construction costs.

Multiplexing

It was fortuitous that during this study a new generation design of 2 to 8Mbit/s multiplex was just being introduced into the network. This equipment capitalised on the advantages offered by Large Scale Integrated (LSI) circuits which made it possible to fabricate the complete multiplex on a "single card" philosophy. This factor and a change towards permitting more commercial freedom in the equipment specification has resulted in significant cost reductions.

Referring back to Table 4, it did not seem unreasonable to assume that the cost target for the 2/8Mbit/s multiplex element of the optical system could be achieved by 1985.

Optical Line Terminal Equipment

The most interesting components in the OLTE are the optical transmit and receive devices. The optical output power level, receiver sensitivity and operating wavelength are all critical factors in the design and ultimate cost of this "optical package". Commercial security is naturally very evident in this area, a factor which made it difficult to be certain about suppliers and the price levels in the market place. Despite this there was evidence to suggest that the "optical package" represented the major cost element of the OLTE. It was also clear that the cost of the "optical package" was critical to any expectations of future price reductions.

Conclusions

The study sought to predict anticipated prices prevailing in 1985. The results indicated that the target prices in Table 4 could be achieved for:

i) Fibre

ii) Cable sheath construction

iii) 2/8Mbit/s Multiplex

It appeared that the cost of the optical devices and thus line terminating equipment represented the major constraint to achieving cost effective systems.

APPROACH TO INDUSTRY

Against the background outlined in the preceeding sections BT formally approached UK cable and transmission equipment suppliers. Industry were advised of the plans to accelerate the network modernisation strategy which in turn offered the prospect for a sizeable fibre market given lower system costs than those currently offered. Individual suppliers were invited to offer likely costs of cables and equipment against a background of their own particular design proposals. They in turn responded to this initiative and in a series of presentations set down their proposals for meeting this need.

In broad terms their response followed a common theme based on a cost effective 8Mbit/s "integrated" terminal design with a supporting multimode fibre cable designed around a "simple" construction theme as anticipated.

FUNDAMENTAL USER REQUIREMENTS

The primary operational objective was to secure a rapid introduction of cost effective systems in relatively large production volumes. In order to achieve this it was thought essential to give individual suppliers commercial freedom in their equipment realisations whilst recognising the need to establish some basic framework of system philosophy.

The overriding operational interest was to secure a simple system philosophy that minimised planning and installation resources. To this end some initial criteria were established as follows:-

i) The previous practice of tailoring fibre loss and bandwidth to individual section lengths would not be adopted.

ii) The grade(s) of fibre chosen would support upgrade to 34Mbit/s by change of terminal equipment alone.

iii) There would be no underground repeaters thus eliminating the need for power feeding over the cable.

iv) The number of surface repeaters would be limited to one, or two at most, to eliminate the need for sophisticated supervisory systems.

v) The alarm requirements would be no more complex than those for existing copper based systems.

In the event separate statements of user requirements were written for cable and equipment respectively. A summary of these initial requirements is given below.

Cable

i) The design must be strong enough to require no special cabling restrictions.

ii) The fibre requirements were specifically specified to be 50/125 micron, 1300nm multimode with the following characteristics

400 MHz/km - 1.5dB/km

600 MHz/km - 1.0dB/km

iii) Cables from different manufacturers must be capable of being jointed together.

iv) Cable would be stocked in standard lengths.

Equipment

i) The basic requirement was for a 4x2Mbit/s system over a nominal 8Mbit/s optical path.

ii) Terminal equipment must be compatible with BT's TEP-1E rack practice.

iii) Input and Output interfaces must comply to standards specified.

iv) The optical, electrical and mechanical aspects must conform to appropriate safety requirements.

v) The system should operate over a path length of 0-10km with 1.5dB/km fibre and 10-15km with 1.0dB/km fibre ie a common maximum fibre loss of 15dB.

vi) The cabled fibre loss between equipment connections must not exceed 24dB.

The overall system is designed to have an optical dynamic range of $>$ 25dB and a typical optical power budget as given below.

LED Launch Power	-16dBm
Receiver Sensitivity	-49dBm
Available Power Ratio	33dB
Fibre loss	15dB
Joint Margin	5dB
Roadworks/Maintenance	4dB
Maximum Cabled loss	24dB
Equipment Design Margin	2dB
Ageing Margin	4dB
Connectors	3dB
Total	9dB

PRODUCTION EQUIPMENT, FIBRE AND CABLE

In July 1984 sufficient confidence had been established with Industry to permit placing substantial contracts for cable and equipment representing some 20,000km of multimode fibre. The various designs are reviewed below.

Equipment

The basic equipment philosophy from all manufacturers follows the trend shown in Fig 2.

Each system end comprises of two cards, one for the optical transmit/receive components plus line coding (1B2B) with the second embracing the 2/8Mbit/s MUX and DE-MUX elements. The standard equipment shelf accommodates up to 4 system ends together with common power and alarm facilities.

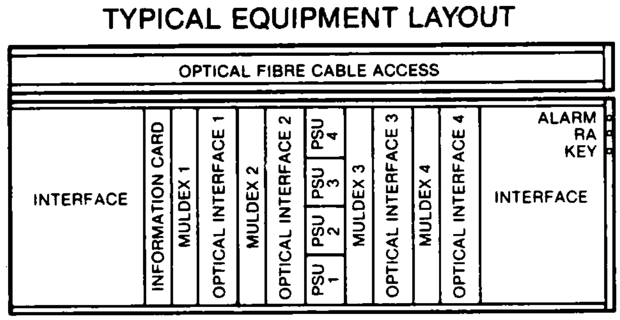
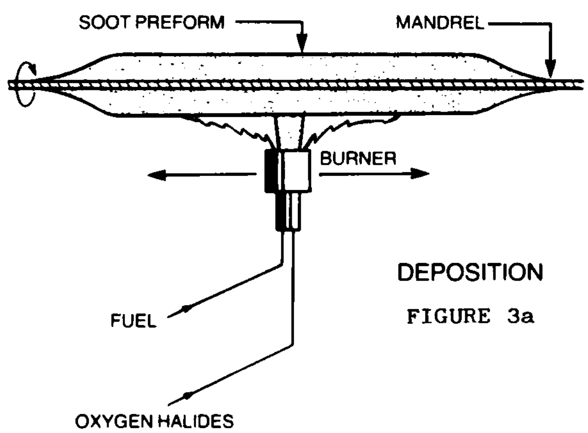


FIGURE 2

Fibre

The multimode fibre was specified and design approved separately. The fibre specification called for primary coated 50/125µm fibre suitable for use in loose tube main cable construction. Secondary coated fibres to the same specification were used in the terminating cable to the equipment interface. The majority of fibre was supplied by a UK company whose production facilities originated from the Corning Glass Works with whom they are in direct partnership. The process uses the outside vapour deposition OVD system. In this method the oxygenated liquid chemical constituents are fed into an enclosed cabinet or "lathe" where they are heated by a burner which traverses latterally depositing the 'soot' on a supporting rod. The input mixture, temperature and the number of passes by the burner are the primary control mechanisms which determine the required index profile. The glass blank of some 0.75m in length and 80mm in diameter made in this deposition process shown in Fig 3a is sufficient to produce some 20-25km of fibre when reheated and "pulled".



DEPOSITION

FIGURE 3a

In this separate pulling process the blanks are mounted at the top of 8m pulling towers, reheated and drawn vertically down to the 125μm size and wound as finished fibre on spools at the base of the tower. This is shown in Fig 3b.

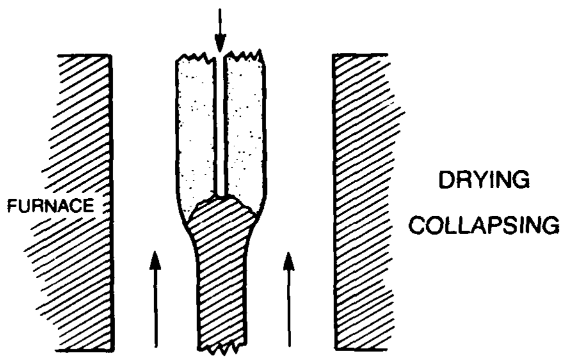


FIGURE 3b

Cables

The aim of this project was to secure a rapid introduction of cost effective designs by persuing a policy of encouraging maximum commercial freedom coupled with minimum BT constraint in design.

Thus the cable specification used for contract purposes concentrated on the fundamental requirements of size, strength, flexibility and overall optical performance. Because the basic system philosophy was conceived to afford system upgrade to 34Mbit/s and the nature of the network is typified by a preponderance of small routes, fibre counts over a range of 2 to 16 fibres were considered adequate to meet all applications.

A dedicated duct bore policy for optical cable was never considered operationally acceptable and therefore it was necessary to specify that cables had to withstand being handled like any conventional design in a mixed duct environment. To afford adequate protection under cabling conditions a minimum cable size of 15mm was specified to limit the possibility of these relatively small cables wedging under large cables already lying in the duct. The other key factor in this equation related to cable strength and its relationship to any residual strain imparted on the fibres whose life expectancy is rapidly degraded due to stress corrosion when under quite low levels of stress. To this end the specification stated that fibres should not be strained by more than 0.25% when the cable is pulled with a force equal to the weight of 2km of cable. Samples of the fibre are tested in the laboratory to determine the tensile strength (by elongation) and predicted service life due to stress corrosion at the earlier fibre design approval stage. The finished cable must also be flexible enough to permit ease of handling during cabling operations and tests at a minimum bending radius of 12 times the cable diameter were specified.

The optical performance of the fibre was specified at the initial stage of the project as a fundamental system parameter. These factors are outlined in the preceeding section of the paper detailing our "Fundamental User Requirements".

Production Designs

During the preparatory study phase of this project outlined previously it was suggested that a hollow tube philosophy represented one obvious way forward to achieve a simple cost effective cable construction provided strength requirements could be maintained. However, in the real world of cable manufacture the design, production and performance aspects are complex, varied and exhibit a considerable interdependance between the parameters involved. Not least of the cable makers concerns is the level of investment in new plant required and the depreciation overheads which follow.

In the event our four major UK cable manufacturers offered differing design solutions which can be broadly categorized as follows.

i) Hollow tube with fibre ribbons

ii) Central core with fibre units

iii) Central core with open slot extrusion

iv) Central core with integral slot extrusion

The target diagrams for each cable design have been collated to assist comparison and are illustrated towards the end of the paper. A brief review of each design is given below.

Hollow Tube with Fibre Ribbon

The concept of this design was to introduce the fibre elements longitudinally into the protective sheath in a single process with adequate stress relief to the combination. The "ribbon" or "tape" array of fibres was developed to allow up to 8 fibres to be laid side by side and bonded together using an acrylate similar to that used for the primary coating of fibres. The ribbon is pre-formed to take on undulating profile along the hollow tube to ensure the required excess fibre length and strain relief is achieved. The "set" of this undulation is achieved using two fine copper wires along the outside edges of the ribbon. In production the ribbon is made off-line to ease manufacture, minimise the consequences of fibre breakages and provide isolation from the slower sheathing process. The corrugation of the ribbon and subsequent sheathing operations are completed as a single production pass. The required longitudinal strength is provided by incorporating bundles of glass fibre elements into the sheath wall providing a flexible cable.

Central Core with Fibre Units

The supplier of this design was one of the first to develop the hollow tube philosophy in conjunction with secondary coated fibres and these cables have been successfully used in the network in their light armoured version. However the final form of construction chosen for our main cost effective cable orders followed the more traditional central strength member and stranded fibre units approach.

In this particular design four primary coated fibres are loosely packaged in a thermoplastic tube to form the unit. Four such units plus two dummy fillers and the metallic pair are stranded around the central compacted steel strand strength member. The internal diameter of the unit tube and the stranding lay of the units are carefully selected to control the amount of excess fibre and resulting strain relief. In order to reduce the pneumatic resistance the tube fillers each have a longitudinal slot cut in them. The tubes are finally protected with a paper belt and polyethylene sheath containing an aluminium laminate moisture barrier.

Central Core with Integral Slot Extrusion

This construction provides another basic low cost cable design with potential for a one-shot production process. The design has the same central compacted steel strand strength member around which is extruded a closed integral construction providing 4 slots in which the fibres are contained. The extrusion is laid over the core with an oscillating twist to provide the required excess fibre and strain relief. Selected slots are allocated to carry the pair of insulated copper wires used for the engineering speaker facility. Access to the fibres for jointing purposes is provided by easy tear strips in the periphery of each slot. This part of the production process is followed by the application of the normal aluminium moisture barrier tape and polythene outer sheath. The two parts of the process could be tandemised and considered as a single pass operation.

Central Core with Open Slot Extrusion

This cable is based on the well proven Northern Telecom design and comprises a central steel strand core around which is extruded an open slotted construction with six channels which follow a reverse helix path along the length of this member. Four of the slots contain the fibres with the remaining two allocated for the insulated copper wires. To hold the fibres and conductors in place during manufacture two binding yarns are applied in opposite directions. A longitudinal wrapping is applied over this "core" followed by the aluminium plastic laminate moisture barrier. The outer sheath in common with all other designs consists of a layer of black polyethylene.

INSTALLATION PROGRAMME

The overall objective of this project which started in 1983 was to trigger a rapid introduction of cost effective junction network optical systems. In July 1984 BT placed its first main contract for these system comprising 20,000 fibre km of cable and 2500 equipment ends representing approximately 25% of the annual junction provision programme. Follow-on orders for a further 40,000 fibre km and 3000 equipment ends have also been placed.

Cable and equipment from the initial order is now being installed by BT field staff and the first system was successfully brought into service back in January this year. There have been no reports of installation difficulties associated with the cabling of long lengths and the only area of anticipated debate relates to interpretation and analysis of joint loss results.

FUTURE SINGLE MODE SYSTEMS

During the last three months we have been studying with UK industry and BTRL the implications of moving to single mode fibre based systems. The price of single mode fibre has fallen dramatically over the last three years and this factor coupled with its ability to support system speeds of 140Mbit/s and beyond makes it a very attractive transmission bearer. Unfortunately, the cost of exploiting such bandwidth potential can be significant and directly dependent on the price and availability of suitable optical transmitting devices.

The various aspects of the overall system equation are reviewed as follows.

Single Mode Fibre

The price of single mode (SM) fibre has fallen quickly in response to world demand and increasing confidence of production. The relative price trends of single and multimode (MM) fibre suggest that equivalence with multimode is anticipated during 1986 with prospect of savings in subsequent years.

It is interesting to note that our major UK fibre supplier now produces three times more SM fibre than MM. With high throughput and simpler processing SM fibre should potentially be the cheaper product.

Cable Design

There is confidence that our current range of cost effective optical cable designs can be used with SM fibre and thus there is no additional cost penalty anticipated in this area.

Equipment Philosophy

The primary aim is to introduce SM systems with marginal or nil cost penalty when compared with

the existing MM systems previously described. Our present cost effective 4x2Mbit/s system is based on fibre qualities deliberately chosen to give 40MHz bandwidth with a loss of not greater than 15dB excluding joint losses, allowing a 34Mbit/s capability over 15km. Strategic planning of the network requires that a 15km system reach between regenerators should be maintained.

The lowest cost equipment option is to use the present 4x2Mbit/s LED based optical terminals over new SM fibre sections. Unfortunately the LED devices are supplied with short MM fibre pigtails of 50μm core diameter. When this is coupled to the very much smaller 8μm core diameter of the SM main cable fibre there is a considerable loss of optical power at the transition. In essence this calls into question the distance one can confidently plan without using repeaters and incurring further cost. Present studies indicate that 10km may be a practical limit using this approach but with this constraint a large proportion of our network requirements could still be satisfied.

Alternative Device Options

For route lengths in excess of 10km at 8Mbit/s and all junction demand at 34Mbit/s higher transmit power devices are essential. There are several options available.

i) Higher power LEDs with MM pigtails

ii) LEDs with SM pigtails

iii) Lasers

The first two options can be obtained at some cost penalty to give a small improvement in system reach. However, the use of lasers offer the most attractive solution providing more than adequate power for all network requirements. Unfortunately the present cost of lasers is prohibitive and a constraint to a more widespread application of SM fibre. As a result we are currently in debate with optical device manufacturers to assess the prospect of obtaining "low cost" laser devices for short haul applications.

CONCLUSIONS

The overall network objective in 1983 was to precipitate a rapid introduction of short haul junction multimode optical systems that were price competitive with the traditional copper based PCM solutions. In a little over 12 months from the start of this project BT placed contracts for 20,000 fibre km of cable and 2500 terminal ends which are now as complete operational systems being progressively brought into service.

During this period the price trends in optical fibre production have changed dramatically and BT is now actively pursuing the steps necessary to afford a rapid introduction and exploitation of single mode fibres for short haul network applications.

ACKNOWLEDGEMENTS

Acknowledgement is made to the Director of Engineering of British Telecom Local Communication Services for permission to publish this paper.

Mr Robbins is Head of the Junction Network Operations Section of British Telecom Headquarters. He is responsible for providing support to forecasting, planning and works staff in the local District offices and identifies the need for, and sponsors the development of new transmission systems. He is a Chartered Engineer and a Member of the Institution of Electronic and Radio Engineers.

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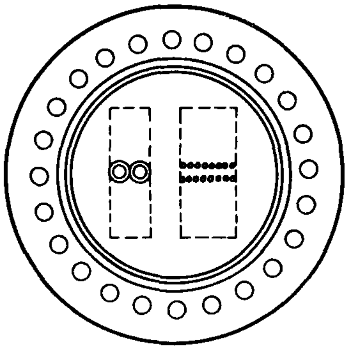
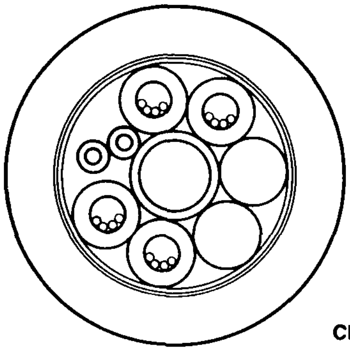
HOLLOW TUBE-RIBBON DESIGN



- Optical Fibre ribbon(s) of approximate sine wave form with an amplitude (peak to peak) of approx 6mm and wavelength of approx 40mm.
- Two 0.6mm diameter insulated Copper wires applied in the same way as the fibre ribbons.
- Paper tape to nominally 175µm thickness.
- Identification tape.
- Moisture barrier of 150µm thick Aluminium tape coated on both sides with polyethylene.
- Black polyethylene sheath incorporating bundles of glass yarn tension relief elements.

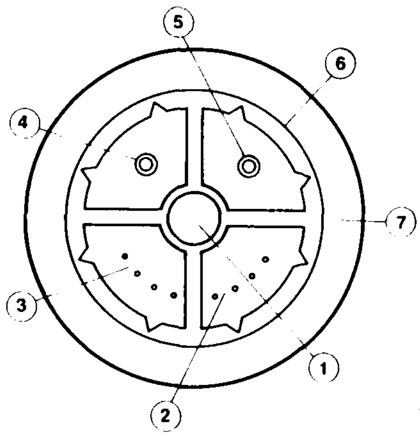
STRANDED UNIT DESIGN



Units consisting of 4 primary coated graded index fibres within a polypropylene tube, laid up around a polyethylene sheathed high tensile steel strength member, with coloured marker fillers and a Ø.6mm polyethylene insulated pair. Paper tape lapped and polyethylene aluminium laminate sheathed.

For the 4, 8 and 12 fibre cables, the superfluous fibre units are, replaced by yellow polyethylene fillers.

CLOSED INTEGRAL CONSTRUCTION



1. Compacted Steel Strand
2. Optical Fibres
3. Optical Fibres
4. Insulated Ø.6mm Copper Wire
5. Insulated Ø.6mm Copper Wire
6. EASY Tear Polymer Extrudate
7. Moisture Barrier Black Polyethylene Sheath

OPEN CHANNEL DESIGN

1
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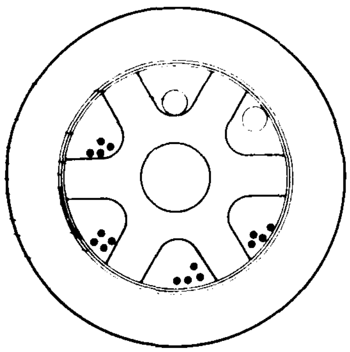

1. Insulated copper wire
2. Optical fibre
3. Open Channel Member with central steel strand
4. Binding yarn
5. Wrapping tape
6. Identity tape
7. Ripcord
8. Aluminium plastic laminate
9. Polyethylene sheath

HIGH-PERFORMANCE OPTICAL FIBER CABLE COVERAGE THROUGHOUT JAPAN

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Abstract

This paper describes an outline of high-performance optical fiber cable used by NTT and the most recent progress for the Information Network System (INS).

Single-mode optical fiber cable (8400 km) and graded-index cable (1800 km) have already been installed into trunk lines. The major trunk line of single-mode cable extends the length of Japan and is about 3400 km long, including 72 km of submarine cable. Improvements in optical loss were obtained, which lead to a maximum repeater spacing of 40 km. Graded-index cable is introduced into medium-haul intra-city transmission lines.

At Tsukuba Expo'85, subscriber optical fiber cable has been introduced in commercial use. High-density subscriber optical fiber cable of five-fiber ribbon structure and other related technological developments have been advanced. These developments will meet the increasing demand for broadband services, such as video and high-speed digital transmission.

1. Introduction

Optical fiber cable has been introduced into many fields of telecommunications because it offers significant advantages, such as low attenuation, wide signal transmission band, light weight and small diameter.

NTT started the study of optical fiber technology since 1966 and introduced the first optical transmission system using graded-index optical fiber cables in 1981. Graded-index optical fiber cable has been introduced mainly in medium-haul intra-city transmission lines. Its total length is about 1800 km.

Single-mode optical fiber cable has such superior optical loss and transmission band characteristics that it has been applied to long-haul large capacity main transmission lines. Large capacity transmission lines using single-mode optical fiber cables have been introduced since the beginning of 1983. In February 1985, the major trunk line was completed. It extends the length of Japan and is about 3400 km long, including 72 km of submarine optical fiber cable. Some side lines, which extend from the major trunk line, have also been laid and the total length of single-mode optical fiber cable is about 8400 km at this time. These transmission lines form the telecommunication highways for the Information Network System (INS).

Field trials of optical fiber cable subscriber loops, started in the Musashino and Mitaka areas in 1982. They lead to the INS Model System which involves a total of 2000 monitors. High-speed digital data and broadband services, such as TV conferencing and color facsimile, are provided in this system. Based on techniques developed in these extensive trials, commercial tests on subscriber optical fiber cable started in April 1985 at the site of Tsukuba Expo'85 and at other exibition sites throughout Japan. Subscriber optical fiber cable has also been placed into commercial use for digital transmission services at up to 6.3 Mb/s and for video transmission services at 4 MHz.

This paper describes the status of optical fiber cable technology at NTT, including commercial test results, the most recent progress, and future trends towards the realization of INS.

2. High Performance Transmission Lines Running through Japan

2.1 History of High Performance Optical Transmission Line Development

The introduction of optical fiber cable started with trunk networks because they have relatively simple network structures as well as economical advantages due to long repeater spacing and large transmission capacity.

The first optical fiber cable put into practical use in Japan was for transmission systems such as the F-32M and F-100M. It featured graded-index optical fiber. Its commercial tests started in the spring of 1981 and since the spring of 1983 it has come into regular use. Graded-index cable has also been used in the F-6M

transmission system, which employs wavelength division multiplexing technology, since 1983.

Single-mode optical fiber cable is expected to be used in long-haul, large capacity transmission lines. NTT started commercial tests on single-mode optical fiber cable for the F-400M transmission system in February 1983. This system was introduced as the main transmission route extending the length of Japan from Asahikawa in Hokkaido to Kagoshima in Kyushu.[1] In February 1985, this route was completed and will be the backbone of INS.

In the submarine sections of this route, a non-repeater submarine transmission system was introduced. Submarine optical fiber cable must have higher reliability than land cable. For this purpose, proof tests are carried out for submarine optical fiber cable under the condition of 1.0% elongation distortion, although proof tests are done for land cable under the condition of 0.5% distortion.

During commercial tests on single-mode cable, NTT investigated a variety of optical fiber cable performances, including the influence of installation on its optical characteristics and the efficiency of its installation work. As shown in Fig. 1, optical loss after installation was found to be sufficiently low at an average loss of 0.70 dB/km including splicing losses. The loss increase caused by installation was negligibly small, and showed an average loss increase of less than 0.01 dB/km. In single-mode optical fiber splicing, the power monitoring method was used to allign core axes. Using this method, a 0.11 dB average splicing loss and a 22 minute average splicing time were realized. The results of the commercial tests on optical fiber splicing can be seen in Fig. 2.

During these commercial tests, improvements in optical fiber loss and in emitted power of the optical devices were obtained. These allowed extending the maximum repeater spacing from 34 km to 40 km. Moreover, an optical fiber splicing machine using the direct core observation system has been developed. The appearance of the machine is shown in Photo. 1. In this system, the optical fibers are monitored by a TV camera installed in the splicing machine and the core is identified by visual analysis and the core areas are aligned by micro-computer control. This method requires only one working point in the splicing manhole, compared to the conventional power monitoring method which requires three working points; one in the telephone office, another in the splicing manhole and the other in the power receiving manhole.

As the application area of single-mode optical fiber cable has extended into that of graded-index optical fiber cable, the specifications of graded-index optical fiber were modified in February 1985. Three grades of graded-index optical fiber cables, which have 500, 300 and 100 MHz·km bandwidths, have been introduced for medium-haul intra-city transmission lines. Conventional 900 and 700 MHz·km grade cables were displaced by single-mode cables. 500 and 300 MHz·km grades of graded-index cables are used for the F-32M system and 100 MHz·km grade cables are used for the F-6M system.

Up to now, more than 10,000 km of optical fiber cable have already been installed into trunk networks throughout Japan. The introduction status of optical fiber cable in NTT is shown in Fig. 3.

2.2 Optical Fiber Specifications and Applications

Graded-index and single-mode optical fiber parameters are the same as CCITT Recommendation G651 and G652. Three grades of bandwidth characteristics such as 500, 300 and 100 MHz·km are specified for graded-index optical fiber to establish economical intra-city networks. In both the F-32M and F-6M systems, 20 km repeater spacing can be realized using these kinds of graded-index optical fiber cables. This repeater spacing can cover more than 95% of their application routes. 500 MHz·km grade cables are also used for the short distance F-100M system.

Single-mode optical fiber cable has such superior bandwidth characteristics that only its optical fiber loss characteristics are specified. Two grades of optical loss characteristics are prepared. Recently, single-mode optical fiber, which has an about 0.4 dB/km average loss, has been efficiently produced due to the progress in fiber fabrication technique. As a result, high grade single-mode optical fiber guarantees optical loss to be within 0.5 dB/km for 90% and 0.65 dB/km for 100% of the fibers. The 90% loss value of low grade single-mode optical fiber is 0.8 dB/km and the 100% loss value is 1.0 dB/km. These grades of single-mode cables are applied to the F-400M and F-100M systems according to the total loss requirement of the route. The most suitable light wavelength for single-mode optical fiber has been determined by optical loss and chromatic dispersion characteristics. The lowest optical loss is obtained at about 1.30 μm and the minimum chromatic dispersion is obtained at about 1.32 μm. Based on these characteristics, the most suitable wavelength has been determined as 1.31 μm.

The specifications of graded-index and single-mode optical fiber cables are shown in Table 1. Fig. 4 sums up the application of optical fiber cables in NTT.

3. Large Scale Introduction into Subscriber Loops

3.1 History of Subscriber Optical Fiber Technology Development [2]

The first application area of subscriber optical fiber cable was small-scale leased lines between two points for broadband and/or high-speed digital services. This network structure resembled that for trunk networks. Consequently, the technology for trunk networks could be applied to suscriber optical fiber cable of this application area. In 1982, graded-index subscriber optical fiber cable was introduced into commercial use to provide video transmission services over broadband leased lines.

The second stage development is leading toward optical subscriber networks between telephone offices and unspecified customers. For expanded introduction into subscriber networks, the following characteristics must be taken into consideration.

(1) Low grade optical fiber is applicable as the lengths of subscriber lines are shorter than those of trunk lines.

(2) Optical fibers must reach all subscribers, without any repeaters although signal multiplication technology can easily be applied to trunk lines.

(3) The network structures are more complex than those of trunk networks and different kinds of subscriber cables are needed in accordance with their application environment.

(4) Easy reconnection techniques are needed to rapidly respond to subscriber demand.

To establish economical and flexible optical fiber cable systems, the technology for cost reduction, higher fiber density, easy cable branching, dropping and splicing, etc., has been advanced.

Following the field trials in the Musashino and Mitaka areas. NTT has devoted great effort to construct the INS Model System covering these areas and the Kasumigaseki area in downtown Tokyo. In 1984, large scale monitor tests involving a total of 2,000 monitors were started. This system provides high-speed digital data and broadband services, such as TV conferencing and color facsimile.

At Tsukuba Expo'85, the international exposition held in Japan since March 1985. NTT has provided diverse advanced telecommunication services for public communications and control operations within the exposition site. For these purposes, commercial tests on subscriber optical fiber cable started in April 1984 at the site of Tsukuba Expo'85 and other exibition sites throughout Japan. Subscriber optical fiber cable has also been introduced for digital transmission services at up to 6.3 Mb/s and for video transmission services at 4 MHz.

3.2 Developmental Status for Commercial use [3]

The maximum number of optical fibers required in a commercial cable was determined to be 100 according to predicted optical fiber demand. The transmission rate is expected to be 100 Mb/s from the viewpoint of future video transmission systems (PCM video). In order to economically achieve this transmission rate for 7 km long subscriber lines, two different grades of transmission bandwidth were prepared for subscriber optical fiber cables. Regular (R) grade fibers are applied for subscribers near telephone offices and special (S) grade fibers are used for subscribers far from them.

Aerial optical fiber cable for distribution use, indoor cable, drop wire, and premise wire were also developed. Optical connectors are necessary in subscriber networks to reconnect optical fibers in feeder distribution cabinets and to drop them to subscribers. To meet these requirements, an optical connector for outdoor use has been developed. As shown in **Fig. 5**, an average splice loss of 0.38 dB was obtained in field splicing work. Furthermore, a closure to easily branch underground cable and an access terminal box for aerial cable have been employed.

3.3 Large Scale Introduction

Recently, the demand for high-speed digital transmission services has rapidly increased. And video transmission systems among business centers has caused a centralized demand for optical fibers. To meet the increasing demand for broadband services, high-density subscriber optical fiber cable consisting of a five-fiber ribbon structure is going to be introduced into commercial use. The structure of the high-density cable compared to that of conventional one can be seen in **Fig. 6**. And related techniques that incorporate a multi-fiber fusion splicing machine and a multi-fiber connector have also been developed. **The results of field researches on multi-fiber fusion splicing machines can be seen in Fig. 7.**

Since the commercial tests on subscriber optical fiber cables realized the excellent bandwidth characteristics, R grade optical fibers can be applicable to 7 km long subscribers, even if they might be designed for the subscribers near from the telephone offices. NTT is investigating the revision of subscriber optical fiber

specifications, including the unification of R and S grades, as shown in Fig. 8. Besides, connector joining is expected to have wider application, to reduce splicing labor and to enhance network flexibility.

4. Future Trends on Fiber Optics

4.1 The New Submarine Optical Fiber Cable

A new submarine optical transmission system, the FS-400M, is going to be introduced to expand the 400 Mb/s main transmission lines to all over Japan. This system uses submarine repeaters that enable long-haul transmission across the sea. Repeater spacing for shallow submarine routes and deep submarine routes is to be specified separately, since the operating wavelength change due to the temperature of the water surrounding the repeater affects the repeater spacing because of the dispersion characteristics change.

A conventional submarine cable can be laid only to a depth of 1500 m, higher proof test specification will be needed in order to apply submarine cable to a depth of 8000 m, since the pulling force during the cable laying will increase tremendously.

Investigations for longer repeater spacing and for larger transmission capacity are also being carried out. They indicate that a repeater spacing of about 100 km will be expected for operation at the 1.5 μm wavelength, since optical fiber has a lower loss at 1.5 μm than at 1.3 μm. Adequate optical fiber design for this purpose is being discussed.

4.2 The Future of Subscriber Optical Fiber Systems

Subscriber optical fiber networks are expected to rapidly expand, especially in business centers in large cities, because of the increasing demand for broadband services such as videotex (CAPTAIN etc.) and video response system (VRS). To provide diverse broadband services for the future, NTT is engaging in development of higher density optical fiber cable (more than 1000 fibers). The application of single-mode optical fiber cable to subscriber networks is also to be investigated considering the future wider application of digital subscriber transmission systems (i.e. digital video and integrated service systems), cost reduction of optical fibers as well as expansion of optical subscriber areas.

Although it is very difficult to forecast the demand for optical fibers, subscriber telecommunication facilities must rapidly respond to new subscriber demands and facility reinstallation should be avoided. Therefore, flexible optical fiber distribution systems and easy splicing techniques are indispensable. In aerial cable distribution, definite-length cable with connectors on both ends will be applied and any fiber in the cable can be dropped to a subscriber from pre-assigned distribution points. Furthermore, connector joining is intended to be applied at all splicing points to enable fast splicing and reconnection.

5. Conclusion

This paper has described the development story of optical fiber cable technology at NTT, including the most recent progress and advanced investigation. Optical fiber networks will form the physical infrastructure of the entire INS.

The next stage toward the full realization of the INS is the integration of various service networks, using digital signal processing technology. The activities described in this paper will eventually lead to providing economical networks which have enough transmission capacity to deal with the digital signals integrated from many services.

Reference

1) T. Uenoya, "High Performance Single-mode Optical Fiber Cable Covering Whole of Japan", J.T.R., Vol. 27, No. 2, 1985
2) H. Ishihara, "Subscriber Optical Fiber Cable Technology", J.T.R., Vol. 26, No. 3, 1984
3) H. Ishihara et al, "Optical Fiber Cable Bandwidth Design for Subscriber Loops", ICC'85 Conference Proceedings, Vol. 2, pp537-539

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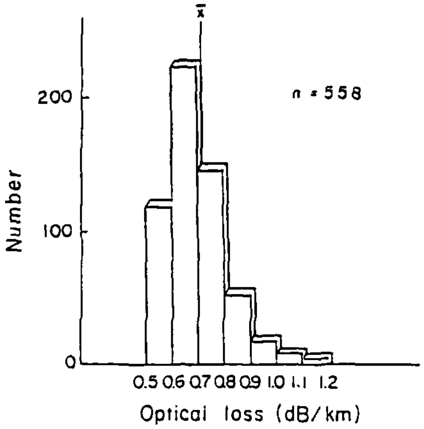

Fig. 1 Optical loss of single-mode optical fibers

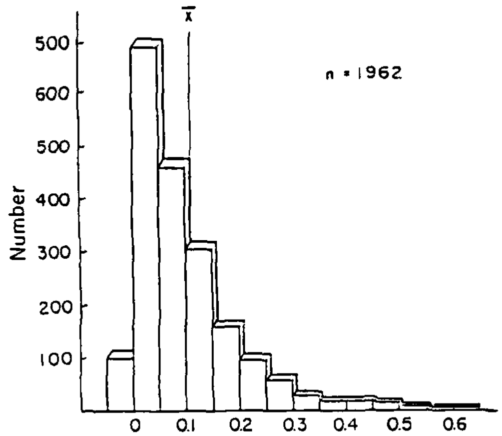

Fig. 2 Splicing loss in single-mode optical fiber fusion splicing

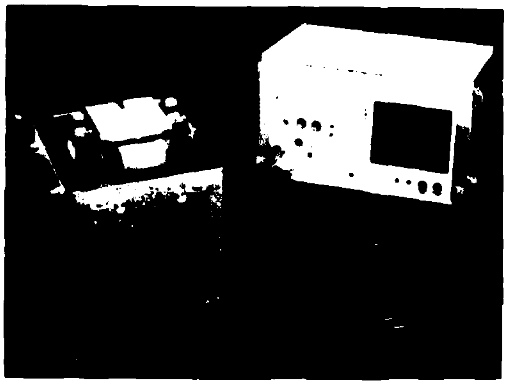

Photo. 1 Direct core observation splicing machine

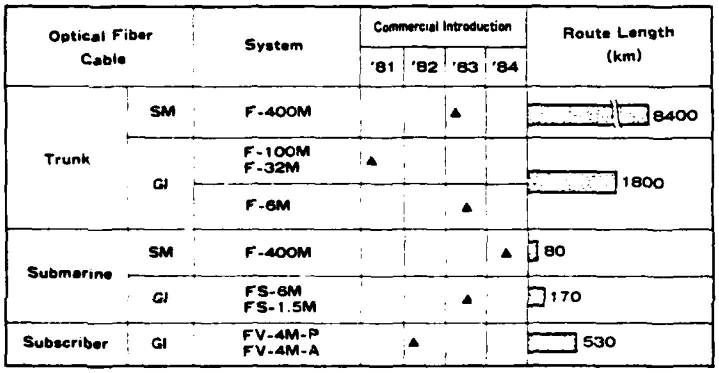

Fig. 3 Introduction of optical fiber cable

Table 1 Specifications of trunk optical fiber cables

Items		GI type Optical Fiber Cable			SM type Optical Fiber Cable	
Grade		500 MHz type	300 MHz type	100 MHz type	0.5 dB type	0.8 dB type
Core Diameter (μm)		50 ± 3			10.0 ± 1.0*	
Cladding Diameter (μm)		125 ± 3			125 ± 3	
Cut off Wavelength (μm)		—			1.10 − 1.29	
Optical Loss (dB/km)	90% Value	≦1.0			≦0.5	≦0.8
	100% Value	≦1.3			≦0.65	≦1.0
6 dB Band (MHz·km)	90% Value	500	300	—	—	—
	100% Value	300	200	100	—	—
Wavelenghth Used (μm)		1.31 ± 0.01			1.31 ± 0.01	

* Mode field diameter

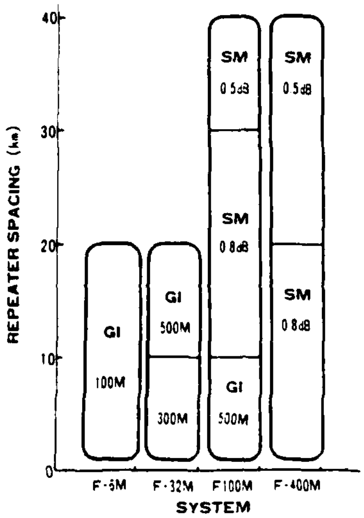

Fig. 4 Application of optical fiber cable systems

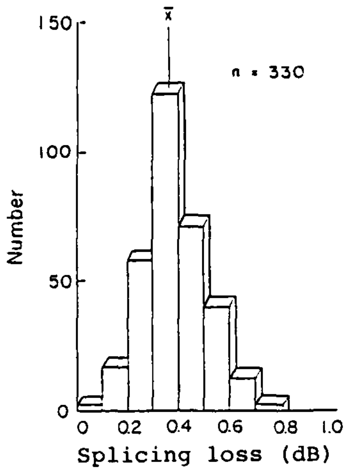

Fig. 5 Splicing loss in optical connector joining

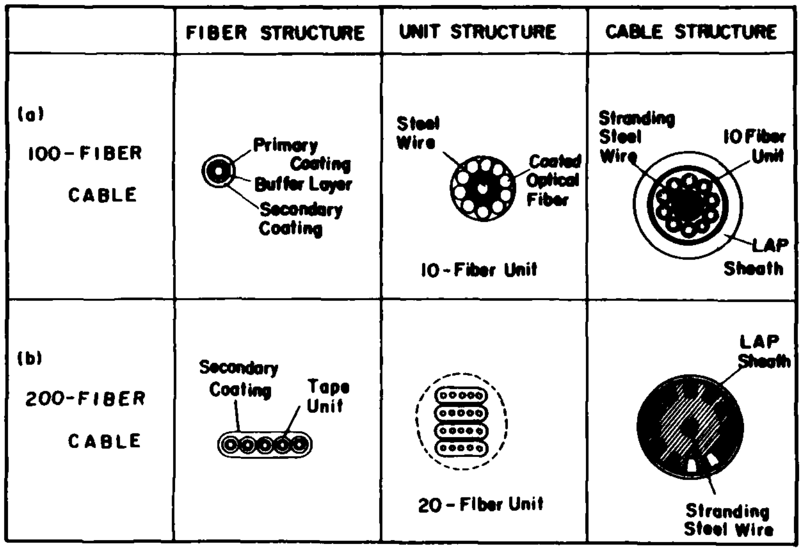

Fig. 6 Subscriber optical fiber cable structure

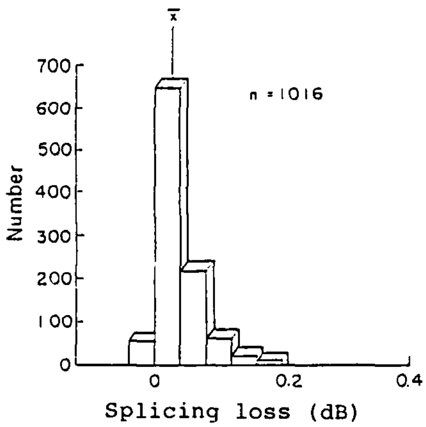

Fig. 7 Splicing loss in multi-fiber fusion splicing

Charateristics \ Grade		R grade	S grade
Optical Loss	90% value	1.3 dB/Km	1.3 dB/Km
	100% value	1.5 dB/Km	1.5 dB/Km
6 dB Bandwidth	90% value	200 MHz·Km	500 MHz·Km
	100% value	150 MHz Km	300 MHz·Km

⇩

Optical Loss	90% value	1.0 dB/Km
	100% value	1.3 dB/Km
6 dB Bandwidth	Average	500 MHz·Km
	Minimum	150 MHz·Km

note) Optical fiber parameters are the same as CCITT Recommendation G651.

Fig. 8 Revision of subscriber optical fiber specifications

CABLE DESIGN AND INSTALLATION TECHNIQUE FOR DIRECT BURIED NON-METALLIC OPTICAL CABLES

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ABSTRACT

The use of non-metallic optical fibre cables for long-haul and rural routes has significant advantages in relation to lightning induced damage, and on routes affected by power line proximity or other electromagnetic interference. The preferred installation technique for such cables is direct burial using cable ploughing techniques, however a number of difficulties were observed which were not previously encountered with traditional metallic cables. Detailed experiments and field trials were undertaken using sensitive fibre strain measurement equipment, and the parameters of suitable cable designs and installation equipment were established. As a result of successful developments in this area, Telecom Australia has standardised on non-metallic filled optical cables for all rural and long distance optical fibre installations.

INTRODUCTION

Like many other Telecommunication Administrations, Telecom Australia is faced with substantial demand for increased digital capacity in its long-haul trunk and rural networks. Single-mode fibre systems have now been established as a cost effective alternative to both coaxial cable and radio systems for these applications, and substantial trans-continental optical fibre links are now planned by Telecom Australia. (Fig. 1).

The use of optical transmission also offers the possibility of a completely metal-free cable that is immune from lightning-induced damage. This is an important consideration over much of the Australian continent, as is the flexibility in route design offered by a cable not subjected to power induction and noise problems associated with power transmission lines. The installation of non-metallic optical fibre cables does however present some problems when compared to the techniques used for their traditional metal conterparts. In rural Australia, as in many other countries, cable ploughing techniques have been established as the most attractive method of installing long-distance directly buried cables. In general however, cable ploughing equipment and techniques have been developed with robust metal cables in mind, and their suitability with the smaller, lighter and more fragile optical cables required detailed assessment.

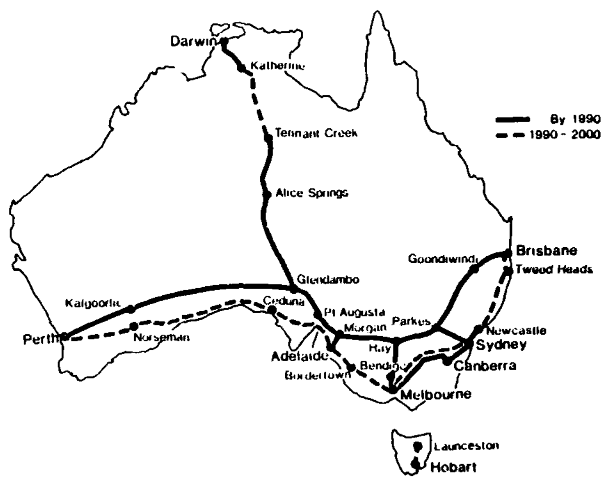

Fig. 1. Optical Fibre Cable Implementation in the Australian Inter-Capital Trunk Network.

CABLE INSTALLATION TRIALS

The use of conventional cable ploughing equipment and techniques designed for metal cables could impose excessive tensions on optical cables which in turn could lead to excessive short and/or long term strain levels in the fibres. Optical fibres are proof tested during manufacture to strain levels of typically 0.5% to 0.8% and may fail instantaneously if exposed to strain levels in excess of the proof-test value. A more insidious problem also arises, in that optical fibres within a cable are susceptible to failure through static fatigue if they are subjected to even small strain levels over a long period of time. (ref.1.)

Whilst cables with extra strengthening materials and metal sheaths have proved successful for such applications, these items add to the cable cost and negate the attractive non-metallic features of the optical fibres themselves.

A series of trials was therefore conducted covering a range of non-metallic cable designs and using a variety of cable ploughing equipment. The elongation of fibres within each of the cables was continuously monitored during the cable installation period, together with a number of other parameters. The results were then interpreted in terms of the variations in cable structural features and differences in the type of cable ploughing equipment used.

Measurement System : The theoretical basis for the measurement system has been established by other authors. The elongation of an optical fibre can be determined from the change in the propagation time of an optical signal along a fibre. Methods employing phase-delay measurements with sine-wave modulated optical sources (references 2-4), and time delay measurements with pulse modulated sources (references 5-7) have been reported. Due to features of the experimental technique employed, it was found that greater resolution of fibre elongation was achieved with the phase - delay method.

The measurement system (reference 8) is illustrated in Figure 2. A loop is formed by splicing two fibres in the cable at the far end (i.e. on the cable drum). A laser diode produces an optical signal which is coupled to one of the fibres. The optical signal is modulated at 200 MHz by a signal from a frequency synthesiser. The returning signal on the second fibre is detected by an avalanche photodiode, and a vetor voltmeter measures the phase difference between the transmitted and received signals.

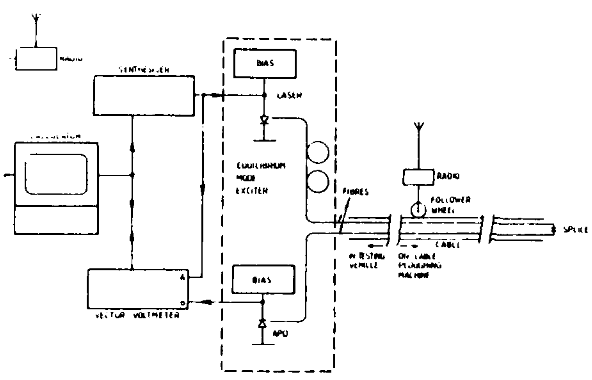

Fig. 2 Fibre Strain Measurement System

The equipment thus described is capable of measuring the fibre elongation relative to its initial state. In order to determine the strain corresponding to this elongation, it is necessary to know the length of cable installed. This was measured by a follower wheel mounted on the cable plough. As each extra metre of cable was ploughed, a data word, representing the cumulative installed length, is relayed by radio from the tractor to the measurement station and entered into the calculator's data record. The stored results can be used to generate a number of records, such as fibre elongation and strain of either residual (steady-state) or transient nature, changes in attenuation, length of cable installed at various times, and cable ploughing speed. In addition, a real-time plot of average strain against length of cable installed can be displayed so that the installation progress can be monitored and installation techniques modified if necessary.

Cables Installed in Trials : Six different cable structures were used in two series of trials in an attempt to establish the effect of cable design parameters on the installation process. The cable structures are shown in Figure 3 and brief details are as follows :

A : Loose tube structure with fibre reinforced plastic (FRP) central strenth member and kevlar peripheral strengthening.

B : Tight stranded structure with six nylon jacketed fibres (0.9mm) and six dummy fillers around a FRP strength member.

C : Spacer-type cable with six nylon jacketed fibres laid loosely in plastic channels between spacers. FRP strength member.

D : Integral type cable with fibres housed in closed slots wihin a polyethylene cartwheel-like structure. FRP strength member.

E : Slotted core structure with FRP strength member.

F : Grooved, spacer type cable with FRP strength member.

Most of the cables used on the trials contained filling compounds. All cables were fitted with an additional nylon outer jacket which is traditional in Australia for protection against ants and termites.

Cable Ploughing Equipment: Trials were conducted using various systems and modifications on existing cable ploughing tractors (typically Caterpillar D9 type) to reduce tensions on cables during installation.

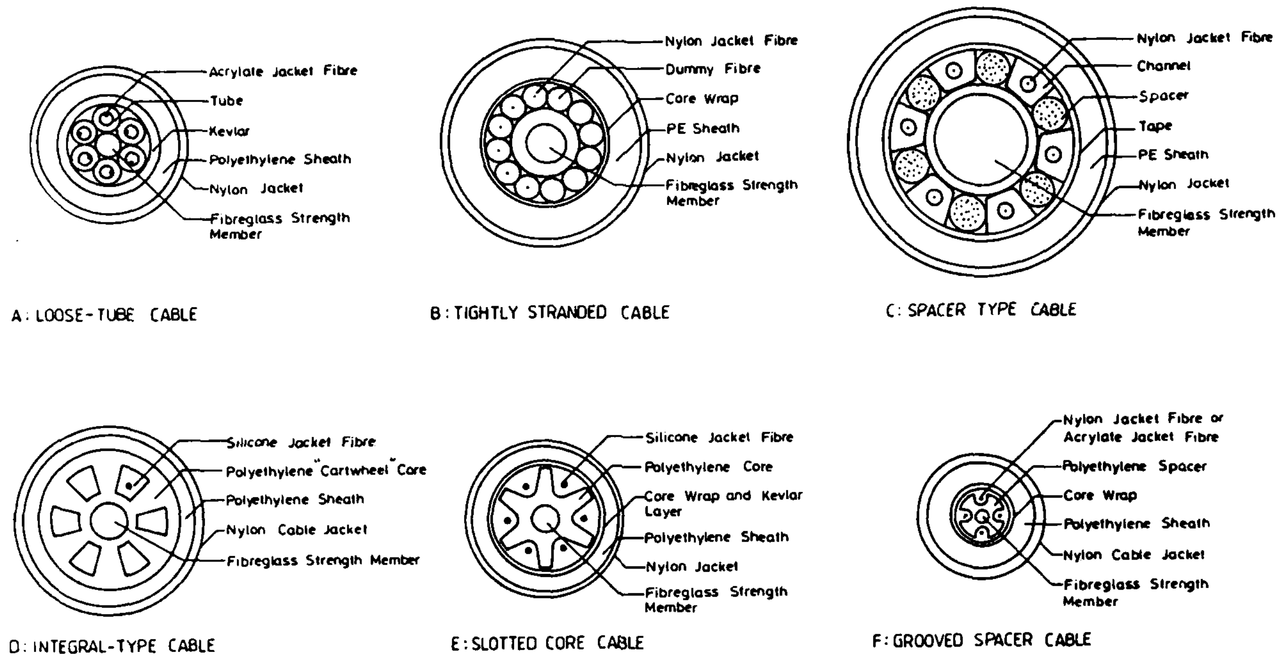

Fig. 3. Cables Installed in Field Trials.

The modifications included:

- Additional tension operated drive capstan at the top of the cable plough box.
- Hydraulic cable drum braking system.
- Automatic Catenary controlled cable drum drive system.
- Teflon lining within the cable plough box.

RESULTS OF FIELD TRIAL

The field trials demonstrated that optical cables with only minimal strength design can be successfully installed using modified cable ploughing equipment without introducing strain levels that might prejudice the fibre lifetime. Two significant cable design features were identified in the trial :

(a) Cables in which fibres are housed loosely, and which may include some small excess fibre length, provide a degree of protection against transient strains.

(b) Cables with high flexibililty can be installed with smaller residual strain levels than stiffer cables.

With regard to installation equipment, conventional ploughing equipment was found to be less than suitable particularly with cables that did not meet the above criteria. Whilst large residual strains were almost totally attributed to the cable parameters of flexibility and strength, transient strains were heavily dependent on the ploughing equipment. Figure 4 shows the elongation of the spacer-type cable (Figure 3C) plotted against the corresponding length of cable installed. This cable showed the highest residual elongation totalling approximately 600 mm over the 920 metres of cable installed. The observed elongation is considered to arise as a result of the tension required to pull the cable around the 90 degree bend at the lower end of the cable plough-box. This cable was quite stiff and radial reaction forces are produced at points where the cable makes contact with the guiding surfaces of the plough-box. These in turn cause friction forces to act on the moving cable at these points of contact, and in overcoming the friction forces, the cable is left with a residual tension. The use of a more flexible cable, or a plough box with increased radius of curvature, would allow the cable to be placed at a lower tension, and hence a lower strain level. Alternatively additional cable strengthening could be used.

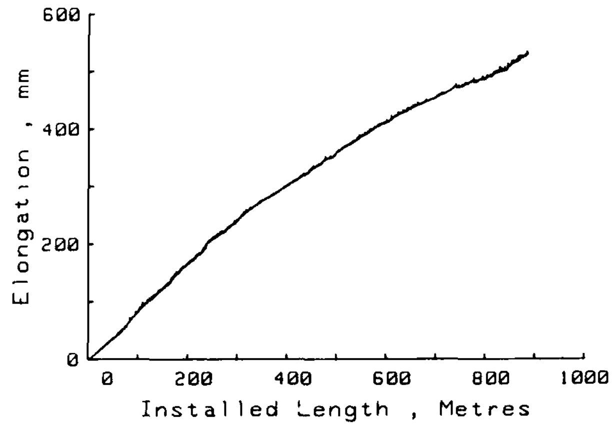

Fig. 4 Elongation versus installed length for Spacer Type Cable 3C

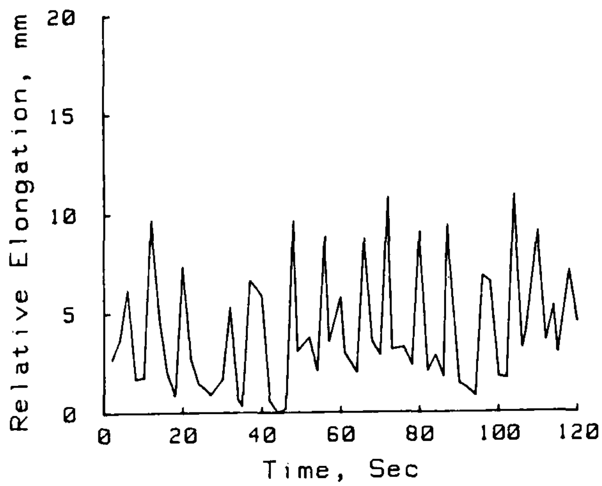

Fig. 6 Expansion of the Figure 5 plot over a two minute interval.

Figures 5 and 6 show the elongation versus time curve for the tightly stranded cable design shown as 3B in Figure 3. Figure 6 provides greater detail showing a 2 minute period starting at approximately the 20 minute mark of Fig. 5. The feature of significance for this cable is the high transient elongations which show as peaks at regular intervals. The installation equipment in this particular experiment did not use any form of drum drive. The peaks occur as tension in the cable increases, and diminish when the tension has reached a level that causes the cable drum to rotate, spilling off excess cable. The elongation values plotted occur basically over the short distance between cable drum and plough box and are values averaged over 2 second measurement intervals. The actual instantaneous elongation values would therefore be higher than those indicated and correspond to a transient strain of up to approximately 0.5%.

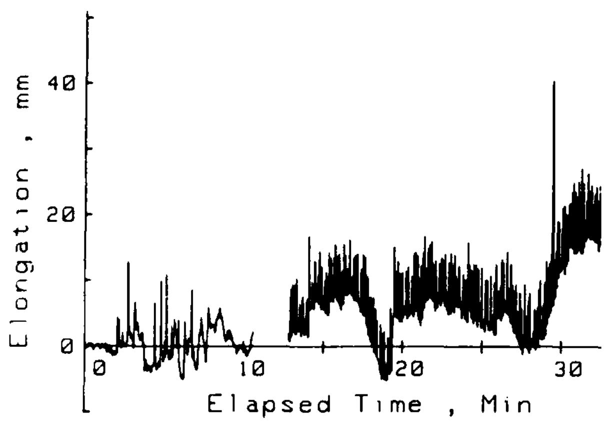

Fig. 5 Elongation versus time for Tightly Stranded Cable

As this level is close to the proof-test level, some action to reduce the transient strain is necessary.

These results indicate the benefits of isolating the cable drum movement and momentum from the installation system. Of significant success in this respect was the automatic catenary controlled drum drive system which was used for the first time in these trials. The use of a reasonable amount of cable slack in the catenary would also assist in diminishing any other effect associated with rapid movements in the tractor itself. Whilst the cable drum brake was of assistance in reducing transient levels, the new catenary controlled drum drive system offered a further improvement in performance to the extent that it effectively concealed any differences in the behaviour of individual designs.

MODIFIED CABLE INSTALLATION EQUIPMENT

The aims in selecting and developing installation equipment were specifically directed towards absolute strain free installation, should this be possible, rather than accepting small strain values, either long-term or transient. As a result of the trials, and with the above aim in mind, the automatic catenary controlled drum drive equipment was chosen as standard equipment for optical fibre cable installation.

Cable Feed Control System

The cable drum driving system that was developed monitors cable demand and then adjusts the speed and direction of rotation of the cable drum so that a constant slack loop of cable is always maintained. The overall configuration of the cable feed control system is shown in Figure 7.

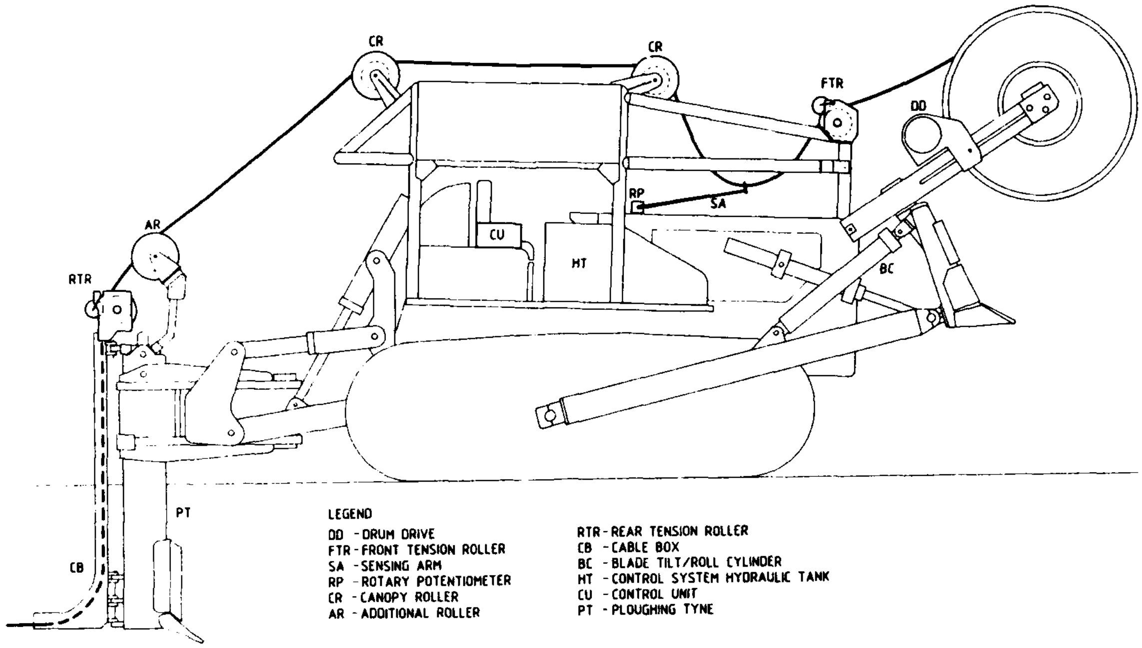

Fig. 7. Schematic Diagram of Modified Cable Ploughing Tractor with Automatic Catenary Drum Drive.

The basic function of the slack catenary loop of cable is to decouple the cable already in the ground and flowing through the cable plough box from the high inertia of the cable drum. The sag in the cable catenary is sensed by a spring-tensioned sensing arm attached to a rotary position transducer which indicates the position of the cable loop. Any deflection of the sensing arm from its normal operating angle results in a signal which causes the electro-hydraulic drum drive to either payout or wind in cable in order to return the sensing arm to its 'normal' angle, and thus maintain the desired sag in the slack loop.

The cable drum, preferably a steel drum, is driven on both flanges via vulcanised rubber wheels. Firm contact between drive wheels and flanges is ensured by two hydraulic cylinders housed within the cable drum carry arms. The control system offers excellent response time between sensing arm deflection and cable payout or wind in. Drum acceleration from 0 to 6 KPH (tractor speed) is possible in only 0.1 seconds through use of the following components:

- A pressure compensated, axial piston pump which is driven off the tractor PTO (Power-Take Off).
- Two high-torque, low speed radial piston motors which rotate the vulcanised rubber drive wheels and thus the cable drum.
- Solenoid operated servo valves mounted directly onto the motor ports. Full hydraulic system pressure is applied to these valves during the cable feed operation, ensuring the fastest possible response of the motors to input control signals.

Overall, this arrangement yields the quickest possible motor reaction to movement of the sensing arm.

The control system has other secondary features:

i. The operator can manually override the system. This is necessary for initial set-up of the cable drum and feeding of the cable through the apparatus.

ii. Tractor autostop. Should the control system malfunction, the tractor transmission is automatically shifted into neutral and the brakes are applied before excessive tension can be applied to the cable.

<u>Other Tractor Modifications</u>: Several other components mounted onto the tractor contribute toward mimimised tension during ploughing of cable:

a. The cable drum is mounted on a hollow spindle rotating on sealed roller bearings.

b. Hydraulically driven rollers in the cable path at the front and rear of the tractor assist the passage of the cable into the plough box. These roller motors develop only a very small torque and are easily stalled. Their overall effect is to keep unwanted slack out of the cable on the tractor, and to balance frictional drag in the feeding path.

c. Stainless steel is used to line the plough box. The expense of teflon lining of the plough box, and the difficulty in securing it to steel, was found not to be warranted.

CABLE DESIGNS

The requirements of a cable design for use in direct buried long distance and rural applications were set as :

- Non-metallic and filled.
- At least 5km drumlengths.
- Able to be installed by cable ploughing techniques.
- Appropriate crush resistance.
- Minimised cost.

In Australia, metallic sheaths are not required for rodent protection, and as a result the standard sheath on traditional pair type cables has been all plastic. Of major concern however, has been the potential for attack by ants, termites or other insects. It has been found that an additional hard nylon jacket applied over the standard polyethyene sheath offers almost total protection against this problem (reference 9). This same sheath construction is seen as satisfactory for directly buried non-metallic optical cables.

As a result of the field trials, it was shown that high flexibility and a loose cable structure gave the best installation performances. Appropriate designs known to meet those requirements include those based on single slotted core concepts (multiple fibres per slot for higher fibre counts) or loose tube constructions (multiple fibres per tube). These designs have been shown to provide excellent characteristics of flexibility through small cable diameter (ie. high fibre packing densities) and have the ability to provide excellent tensile strength, lateral crush and impact protection.

Relevant Cable Specifications related to cable structure are:

Cable Diameter: In order to maximise cable flexibility and lengths accommodated on limited size cable drums, the overall cable diameter shall be minimal and shall not exceed 20mm for cables up to 60 fibre. Cable lengths in excess of 5km are required.

Tensile Strength: The cable shall have a tensile strength to mass ratio of greater than 5 Newtons/(kg/km). Cables with a mass of less than 100 kg/km require a minimum tensile strength of 500 Newton. The tensile strength is defined as the tension required to produce a strain in the fibres at a level of 30% of the proof-test strain. Designs which include excess fibre length therefore have an advantage.

Minimum Bending Radius: The cables shall be capable of meeting the following minimum bending radius requirements without experiencing cable or fibre damage or attenuation increase:

- 10 times cable diameter at no load
- 20 times cable diameter at maximum tensile strength.

Crush Resistance: Cables must be capable of withstanding a long-term crushing force (ie. statically applied lateral load) of at least 10KN/m, and a short term (1 minute) crushing force of at least 20KN/m without experiencing fibre damage or attenuation increase.

Filling Compound Barrier :

One aspect, which is still under evaluation, is the inclusion of an all plastic barrier material between the cable core and the cable sheath to prevent absorbtion by the sheath of oils and other materials contained in the filling compounds. Several materials show promise for this application through their properties of low permeability to oils, and it is proposed that appropriate laminated plastic tapes made from these materials would be bonded to the inside of the polyethyene sheath in a similar way to existing aluminium moisture barrier laminates.

The requirement for these filling compound barriers arises from concerns that absorbed filling compounds may have a longer term effect on the sheath of the non-metallic optical cable or may leave voids or water paths in the cable core.

LOCATION OF INSTALLED NON-METALLIC CABLES

Whilst the use of non-metallic cables will have advantages, significant problems may occur when these cables must be located some time after installation.

A number of locating systems have been examined including metallic tapes, wires and cables layed above the optical cable, however none of these has proved satisfactory.

The most successful technique, which will be used on early installations, uses a combination

of marker posts, buried plastic tape, and electronically detectable transponder pegs.

The highly extendable, non-metallic plastic tape is simultaneously ploughed in about 500 mm above the cable. The tape has warning markings, and is designed to attract the attention of anyone digging above the cable.

A marker post system will also be used. Each post will include a sign denoting optical fibre cable, as well as an accurate, permanent sketch plan showing the cable alignment in relation to the post. The sketch is made just after the tractor passes the post location.

In addition, relocatable passive transponder pegs will be buried above the cable at significant changes of direction, and at pre-determined spacings. The pegs can be accurately located to within 50mm, using a special detector.

It is expected that this combination of systems will ensure that the cable is adequately marked and protected, and able to be accurately located after installation.

CONCLUSION

In countries or areas where metallic cable sheaths are not required for mechanical or rodent protection reasons, non-metallic optical fibre cables can offer significant advantages in relation to lightning damage and on routes affected by electromagnetic induction problems. The costs of these cables could however become excessive if high tensile strengthening elements must be incorporated into the cable designs to cope with the rigours of installation.

As a result of an extensive set of field trials, Telecom Australia has developed cable specifications and installation equipment which will allow low cost non-metallic cables to be installed successfully, and specifically without residual fibre strain. An extensive programme of installation of such cables is now underway and will extend well into the 1990's.

ACKNOWLEDGEMENTS

Many people rendered valuable assistance in the design and conduct of the experiments and trials and their help is gratefully acknowledged. Special acknowledgement is given to the staff of the Optical Systems Section of the Telecom Research Laboratories and to staff in the Queensland Automotive Plant Section. The permission of the Chief General Manager, Telecom Australia, to publish this paper is acknowledged.

REFERENCES

(1) S. Tanaka et al. "Lifetime Design of Optical Fibre Cable for Long Term Use", Sumitomo *Electric Technical Review*, No. 21, January 1982, P. 47-51.

(2) M. Tateda et al. "Thermal Characteristics of Phase Shift in Jacketed Optical Fibres", Applied Optics, Vol. 19 No. 5, 1 March 1980, P. 770-773.

(3) R. Kashyap and M. Reeve, "Single Ended Fibre Strain and Length Measurement in Frequency Domain", Electronics Letters, Vol. 16, No. 18, 29 August 1980, P. 689-690.

(4) S. Tanaka et al. "Precise Measuring Method of Elongation and Residual Strain of Optical Fibre Due to Cabling Process", Seventh European Conference on Optical Communications, Copenhagen, September 1982, P. 6.6.

(5) A.H. Hartog et al. "Variation of Pulse Delay with Stress and Temperature in Jacketed and Unjacketed Optical Fibres", Optical and Quantum Electronics. Vol. 11, 1979, p. 256-273.

(6) O. Kawata et al. "Residual Elongations of Submarine Optical Fibre Cable Laid on the Sea Bottom", IEEE Journal of Lightwave Technology., Vol. LTI, No 1, March 1983, P. 190-194.

(7) T. Kobayashi et al. "Stress in Fibres During Optical Cable Manufacturing Process", Proceedings of the International Wire and Cable Sumposium, November 1978. P. 362-386.

(8) R.W.A. Ayre "Measurement of Longitudinal Strain in Optical Fibre Cables During Installation by Cable Ploughing", Accepted for publication in IEEE Journal of Lightwave Technology.

(9) R.A. Clark & G. Flatau "Development of Nylon Jacketed Telephone Cable Resistant to Insect Attack" 21st International Wire & Cable Sumposium, USA., 1972.

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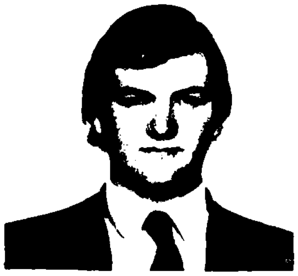

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A NEW WIRE CONNECTOR JOINS A PAIR WITH A PINCH

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Abstract

A new, pair-at-a-time, wire connector has been developed that may be installed with an ordinary pair of pliers. The connectors may be used for making repairs to modular splices, rehabilitating pedestals and splicing small pair count cables. Because of its in-line configuration, it is well suited for splicing with little slack and for making half taps.

Introduction

A new, pair-at-a-time connector has been developed for splicing outside plant multipair cable. The connector is the latest in a series that began with the B-Wire Connector and includes the 700-type connector. The introduction of waterproof cable and aluminum conductors hastened the development of 700-type connectors for joining individual conductors and somewhat later the 710 Modular Connector for joining 25 pair units with greatly improved joining rates. The new connector, coded the 709 Connector, complements a modular joining system by providing a more space efficient and convenient way of splicing a pair of wires with common tools than using individual wire connectors. The 709 connectors' areas of application, salient features, design details and performance are discussed in the sections that follow.

Application

The primary use for the connector is for splicing small pair count cables. The new connector is also particularly well suited for making repairs and rearrangements to existing splices.

Features and Capabilities

A notable feature of the connector is its ability to be installed with commonly available splicers' tools. A pair of snips (for wire trimming) and a pair of long nose pliers (for pressing the connector) are all that is needed. This feature unburdens the splicer from having to transport and maintain a variety of special purpose connector application tools to handle different splicing situations. For splicing larger pair count cables, a magazine type pressing tool is available.

The connector can handle wire sizes from 22 to 26 gauge and comes in either filled or unfilled versions. The arrangement of the contact elements in the connector body allows the wires to be joined in an in-line fashion, thus facilitating splicing with a minimum amount of slack. The connector can also be used for half-tapping.

The connector is extremely space efficient in that it joins two wires in a 0.15"x0.3"x0.95" envelope. The pair-at-a-time feature not only increases space efficiency, but helps preserve tip/ring identity.

Design Details

The heart of the design of the new connector is its new, low profile, split beam, insulation displacing contact element. The low profile allows the element to accept a broad range of wire sizes, yet fit into a small package. The dimensions of the U-shaped element are tailored to allow elastic energy to be stored in its beams during wire insertion. Unlike other split beam contacts, the low profile contact stores energy in both bending and torsion. This feature gives it the compliance necessary to accept a wide range of wire sizes yet be stiff enough in the wire insertion direction to completely remove the insulation from the wire. The energy stored in the contact elements helps insure long term electrical reliability.

Since the connector body is injection molded from clear plastic, it is easy for splicers to verify proper wire insertion. A center rib which runs the length of the connector body assures that the connector will be properly

closed, even when pressed with tools having non-parallel jaws (as is the case with long nose pliers).

The connector housing is fabricated by assembling two separate plastic parts - the cover and base. The two ends of the connectors' cover are separately hinged and thus permit wires entering one end to be pressed independent of wires entering the opposite end. This has a strong positive influence on wire handling efficiency since one pair of wires can be inserted, pressed finger tight and kept under control while the splicer performs a similar operation with the remaining pair of wires. Final connector pressing with the pliers can then be done without the splicer having to contend with positioning the wires. Internal features of the housing provide dielectric separation between the two contact elements, strain relief gripping of the wires and latching that holds the housing parts together.

Half-tapping is done by first terminating the cut or tap pair in one end of the connector. The opposite end of the cover is then removed by twisting it off with ones' fingers or pair of pliers. In its place is inserted a half-tap adapter, through which the through wires have been routed and temporarily secured in place. The half-tap adapter is then pressed in place with pliers thereby forcing the through wires into the contact elements and automatically completing the electrical bridge.

The connector contains two thin walled dimples on its underside to facilitate penetration by test probes. Such penetration permits direct contact with the contact elements.

Performance

The 709 Connector has been subjected to a barrage of tests to characterize its performance. It has been tested to both AT&T standards and REA PE-52. These tests are summarized in Table I. The connector meets all specifications.

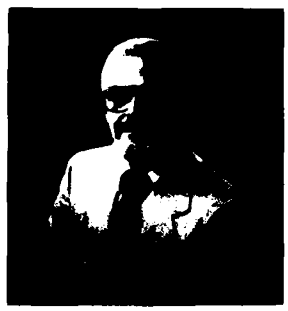
Summary

In a cable joining system dominated by modular connectors, the new 709 Connector provides a quick, inexpensive means for joining small pair count cables and making repairs without the need for special application tools. Its full pair capability helps maintain tip-ring identity and keeps the connector size per pair small. It can be used for making both in-line splices and half-taps.

T. C. Cannon (Tom) is supervisor of the Connector Systems Development group. This group has responsibility for developing standard connectors and tools for splicing electrical and lightguide communication cables.

Tom joined AT&T Bell Laboratories in 1970 and worked in the Safeguard Laboratory. His initial assignment dealt with modeling the behavior of missiles in a tactical nuclear environment. Since that time Tom has worked in Ocean Systems and in Loop Transmission. Some of his activities in Loop Transmission have included analytical modeling of lightguide cables and design of lightguide cable splicing hardware.

Tom did both his graduate work and undergraduate work at Purdue University. He received his Ph.D. in Aeronautical, Astronautical and Engineering Sciences in 1970, with a major in solid mechanics.



Donald T. Smith is a Member of Technical Staff in the Connector Systems Development group of AT&T Bell Laboratories. He is a graduate of Wentworth Technical Institute and has been associated with the development of connector systems from 1960 to present.

TABLE I
Testing the 709 Connector

Test	Source	Method	Requirement	Results
Wire Pullout	AT&T	Tension applied at 2"/min	> 60% of Unjoined 22 ga wire strength	Pass
			> 70% of Unjoined 24 ga wire strength	Pass
			> 80% of Unjoined 26 ga wire strength	Pass
Wire Twist	REA	90° twist left and right while measuring resistance	< 2% resistance variation (includes 4.8 inches of wire)	Pass
Vibration	REA Modified	Vibrate sample in 3 planes, 20 min. ea., 10 to 55 Hz	No momentary opens	Pass
			< 2 milliohm change at 99.99 percent	Pass
Dielectric Strength (wet)	REA	Immerse sample. Increase voltage 500 V rms/sec	> 2500 Vrms	Pass
Dielectric Strength	AT&T	Withstand 60 Hz One minute.	> 3000 Vrms	Pass
Insulation Resistance (wet)	AT&T	Immerse sample 3 days, dry 3 days - repeat 5 times Measure resistance to water @ 100 V DC	> 10^8 ohms	Pass
Insulation Resistance (High Humidity)	AT&T	95% R.H. 30 days cycle temp 32° to 140°F. Sample in lead shot Measure resistance to shot	> 10^8 ohms	Pass
Contact Resistance (Temp Cycle)	AT&T	1024 cycles - -40 to 140°F Measure resistance change	< 2 milliohm change at 99.99%	Pass
Contact Resistance (Thermal Shock)	REA Modified	100 cycles liquid nitrogen to 180°F Measure resistance to change	< 2 milliohm change	Pass

FIGURE 1 THE 709 CONNECTOR IS DESIGNED TO BE PRESSED WITH PLIERS. IT IS SHOWN HERE IN A REPAIR APPLICATION

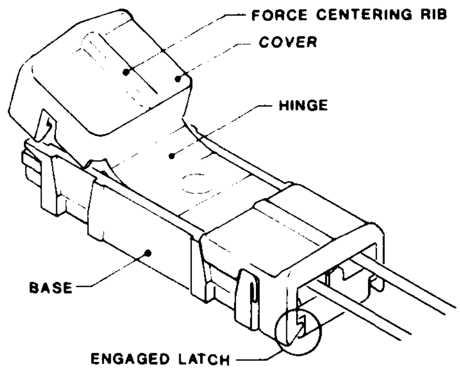


FIGURE 2. THE 709 CONNECTOR HAS TWO INDEPENDENTLY CLOSING ENDS. THIS AIDS WIRE HANDLING.

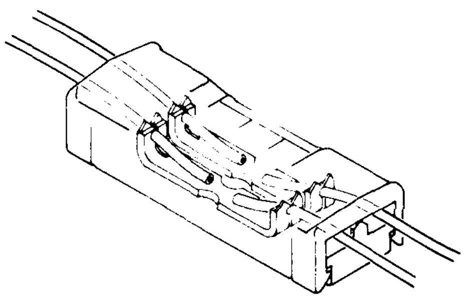


FIGURE 3. TWO LOW PROFILE CONTACTS SHOWN IN A COMPLETED CONNECTION. MOLDED RIBS BETWEEN THE CONTACTS (NOT SHOWN) MAINTAIN DIELECTRIC STRENGTH.

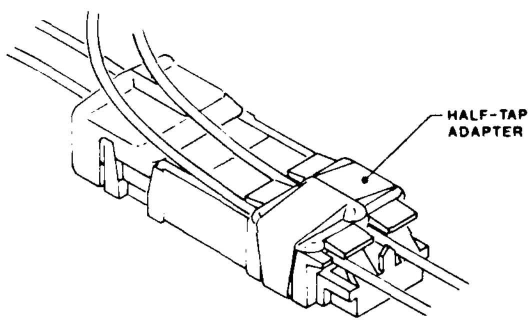


FIGURE 4. THE 709 CONNECTOR IS USED FOR HALF-TAPPING BY REPLACING ONE OF THE HINGED ENDS WITH AN ADAPTER.

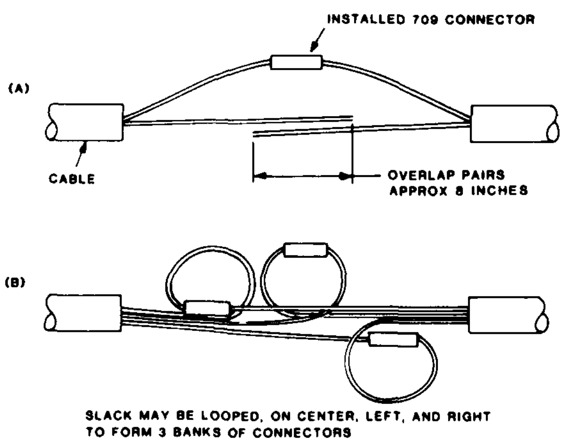


FIGURE 5. A SUGGESTED METHOD FOR AN IN-LINE SPLICE WITH THE 709 CONNECTOR.

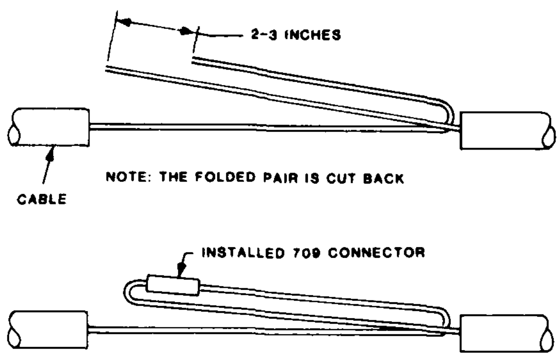


FIGURE 6. THE 709 CONNECTOR MAY BE USED IN FOLDBACK SPLICES.

LOCAL LAUNCH AND MONITOR FOR SINGLE-MODE SPLICING

R. HUGHES, V. SO, & P.J. VELLA

BELL NORTHERN RESEARCH

ABSTRACT

A novel evanescent field coupling technique of injecting light into and out of jacketed single-mode fiber core is described. This technique couples enough light into the guided mode for the alignment during splicing of color-coated fiber. Splice loss of less than 0.2 dB is readily available in the field by this one-man splicing technique.

INTRODUCTION

The last few years have demonstrated a major trend to the utilization of single-mode fiber cables in toll and trunk applications. As a result, there is a need for an efficient method of splicing single-mode fibers. Unlike multimode fiber, single-mode fiber splicing requires a precise core to core alignment to ensure low loss. This is due to the small core diameter, core/cladding eccentricity, and mode-field diameter mismatch. Until recently this alignment was achieved in the field using a straight forward method.

The three station method requires one operator to launch light at the link origin, another at the far end of the cable being spliced onto the link, and of course the splicer. The operator at the far end connects the fiber being spliced to a detector and the optical power level is transmitted to the splicer via order wire. This method is labour intensive, time consuming, and there are the attendant communication problems.

Recent efforts to improve this situation have resulted in two separate approaches. These are visual core alignment and local launch/detect. Examples of the former are the use of core fluorescence (1), the insertion of a beam splitter (2), phase contrast microscopy (3), and vidicon /T.V. monitoring (4). The latter involves bending one fiber to locally launch light and bending the other fiber to locally detect the signal (5).

In order to achieve minimum splice loss the fibers must be aligned to give maximum optical throughput. Local launch/detect methods ensure maximum optical throughput whereas it is not necessarily the case with visual core alignment.

In this paper we are presenting a novel technique utilizing evanescent field coupling to launch light locally into the fiber resulting in a 10 dB improvement in coupling efficiency over conventional bending methods.

THEORY

When a fiber section is bent into an arc of radius R there exists in the plane of the fiber arc a radius R_c (> R) at which the wave vector of the guided mode is just equal to the wave vector k of a plane wave. For distances greater than R_c the field of the guided wave is coupled to the radiation field. The radius R is given by

$$R_c = R\ \beta/k$$

for typical situations (eg. R = 1 mm, β/k = 1.47, R_c = 1.47 mm) $R_c \gg a$, where 'a' is core radius of the fiber, and the field strength of the guided mode is small. Therefore, coupling between the guided mode and the radiation field is small. To improve the coupling efficiency the evanescent microbending coupling technique is used.

The fiber is bent and simultaneously pressed against the hypotenuse of a right-angled glass prism (Figure 1). The wave vector paralled to the fiber axis is now given by $k_{11} = nk \cos \theta$,

where n is the refractive index of the glass prism, and Θ is the angle between the incident beam and the fiber axis. By judiciously choosing n and Θ, one can get $k_{11} \cong \beta$, making the coupling most efficient near the fiber core, where the field strength of the guided mode is maximum. In this fashion about 10 dB improvement in the coupling efficiency is obtained.

DESIGN AND USE

A prototype local launch monitor (LLM) was designed and built based on the evanescent field coupling technique described above. A schematic of the launch block is shown in Figure 2. A modulated laser diode operating at a center wavelength of 840 mm is focussed onto the bend in the launch block. The core light of this fiber is detected via the core of the second fiber positioned in the detect block (Figure 2). A phase sensitive detection scheme provides a net dynamic range of 25 dB and an alignment sensitivity of ± 0.05 dB. The current LLM can be used with most conventional single-mode fusion sets as depicted in Figure 4. It is modular in design consisting of a launch module, detect module and a control unit (Figure 7). Light level during alignment is displayed to one hundredth of a dB on the LCD of the control unit.

TESTS AND RESULTS

The LLM was tested with the Northern Telecom fusion test set to determine its sensitivity to lateral fiber displacement. Once the fibers were aligned to a maximum throughput power, the fibers were displaced by 10 microns in an axis orthogonal to the core axis. One fiber was then scanned along this orthogonal axis through the power peak and 10 microns to the opposite side. The results are presented in Figure 5 where it can be seen that fiber alignment to better then half a micron is achievable.

Both prototype and production units were subjected to technical and field trials. During these trials LLM readings were recorded just prior to and immediately after fusion. It was found that a positive change generally corresponded to a low loss splice.

Figure 6 represents data on splices done with the LLM and an NT fusion splicer. In the case where the pre/post fusion readings decreased, the splice was redone. All the other splices were then measured using the cut-back method. It can be seen on Figure 6 that about 80% of the splices are better then 0.2 dB (in fact, 54% are better than 0.1 dB), and the average splice loss is 0.12 dB. These results confirm that the LLM can give a very good qualitative indication of splice quality.

SUMMARY

The use of evanescent field coupling technique results in a 10 dB improvement over conventional bending local launch methods. Therefore, the LLM can be used for the accurate alignment of color-coated fibers. Technical and field trials have shown that the splice loss achieved is equal or better than the conventional 3 station method. Furthermore, a qualitative indication of splice loss is given by the pre/post fusion readings.

REFERENCES

1) K. TAKETURA, H. YAMAMOTO and M. NUNOKAWA, "Novel Core Alignment Method For Low-Loss Splicing of Single-Mode Fibers Utilizing UV-Excited Fluorescence of Ge-doped Silicon Core". Electron Lett. Vol. 18, No. 16, pp. 712, 1982.

2) K. ZMON, and M. TOKUDA, "Axis-Alignment Method for Arc-Fusion Splice of Single-Mode Fiber Using a Beam Splitter". Opt. Lett. Vol. 8, No. 9, pp. 502, 1983.

3) T. HAIBARA, M. MATSUMOTO, T. TANIFUJI and M. TOKUDA, "Monitoring Method For Axis Alignment of Single-Mode Optical Fiber and Splice Loss Estimation". Opt. Lett. Vol. 8, No. 4, pp. 235, 1983.

4) O. KAWATA, K. HOSHINO, Y. MIYAJIMA, M. OHNISHI, and K. ISHIHARA, "A Splicing and Inspection Technique for Single-Mode Fibers Using Direct Core Monitoring". Journal of Lightwave Technology, Vol. Lt. 2, No. 2, pp. 185, 1984.

5) C.M. DeBLOK and P. MATTHIJSSE, "Core Alignment Procedure for Single-Mode Fiber Jointing". Electron. Lett., Vol. 20, No. 3, pp. 109, 1984.

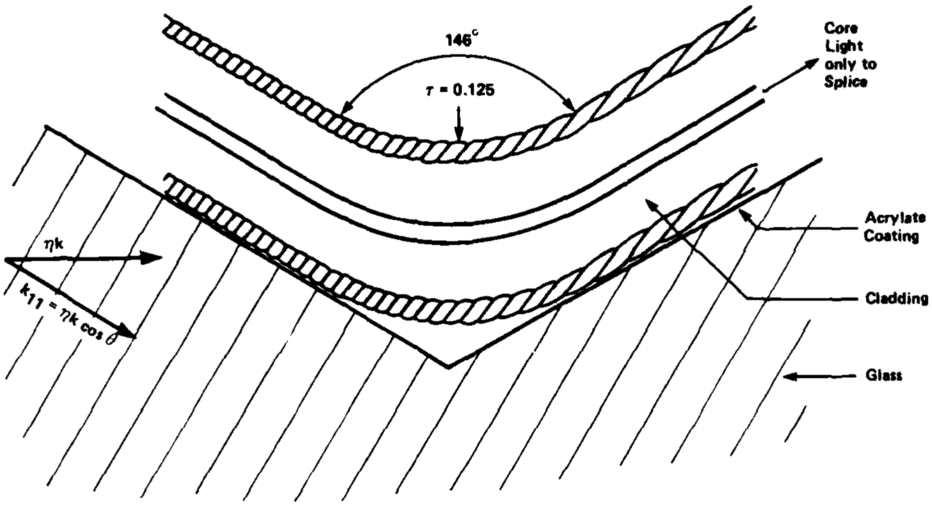


Figure 1 Principle of Operation – Local Launch and Detect

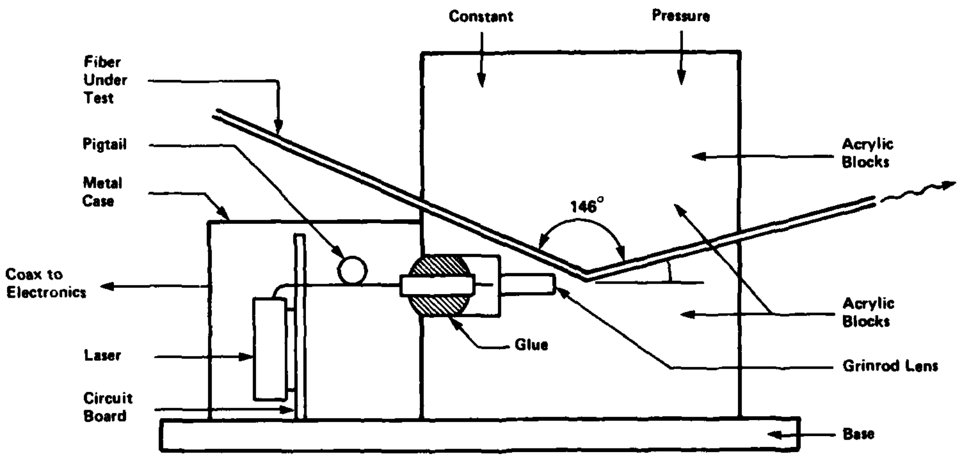


Figure 2 Schematic of Launch Block

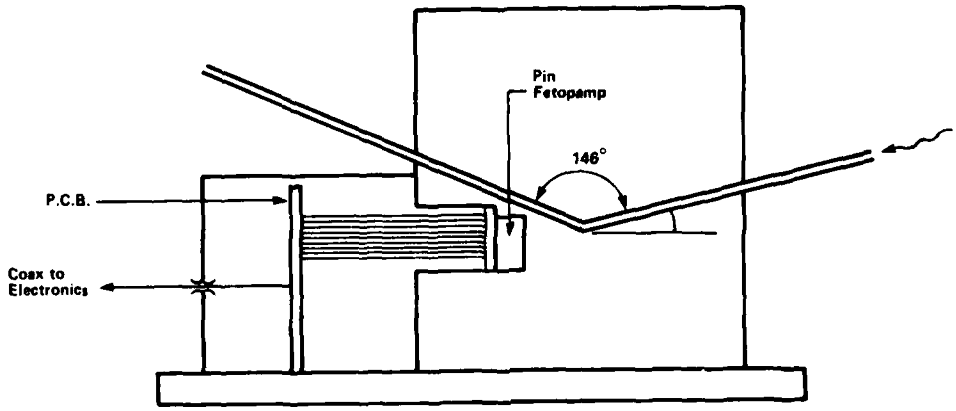


Figure 3 Schematic of Detect Block

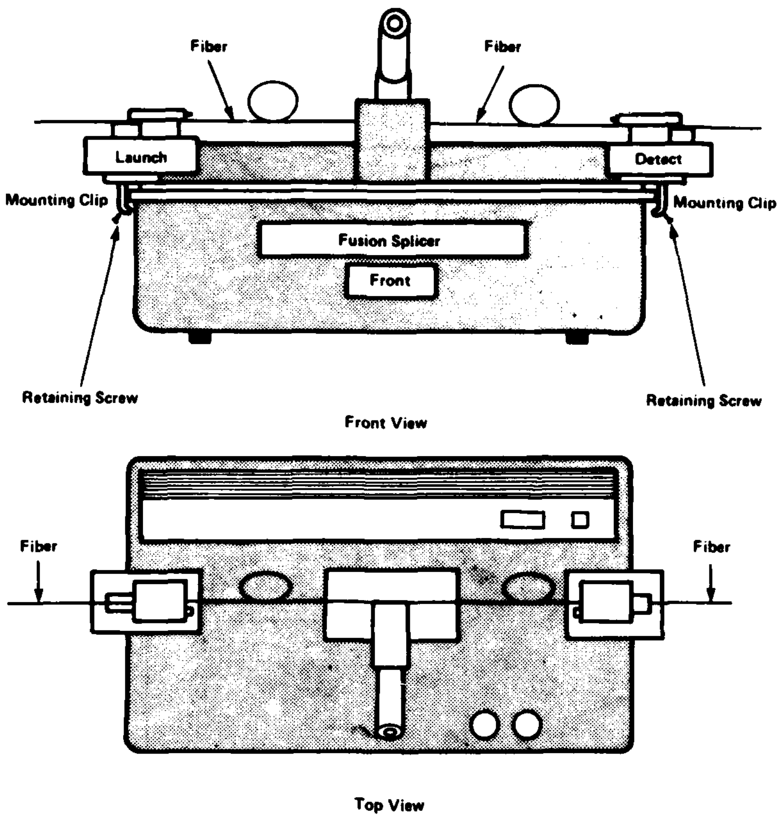


Figure 4 Splicing with LLM and Fusion Set

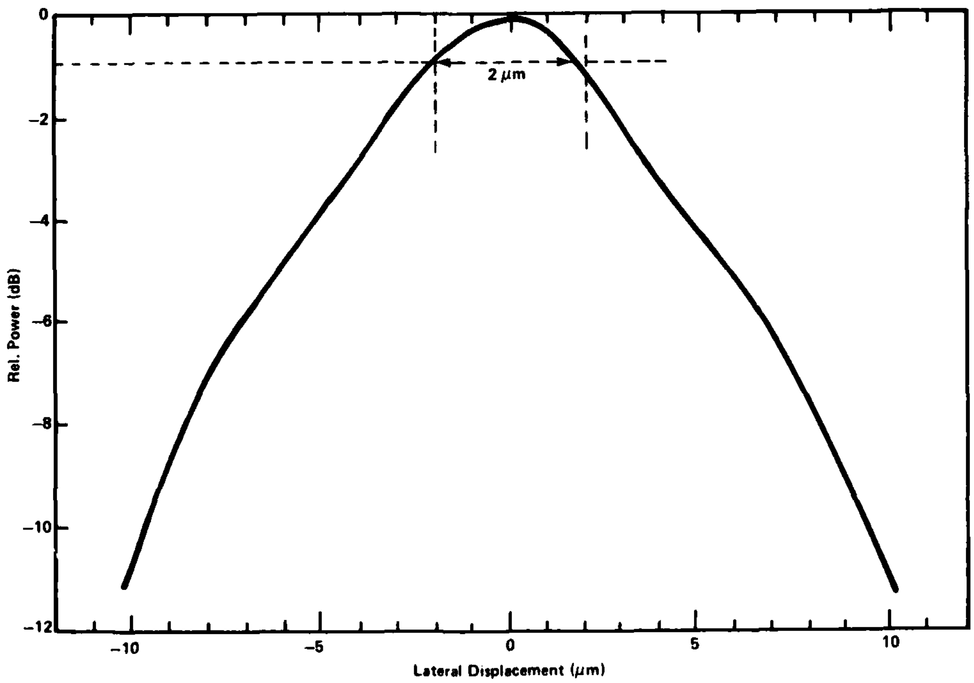


Figure 5 Optical Power Through Splice

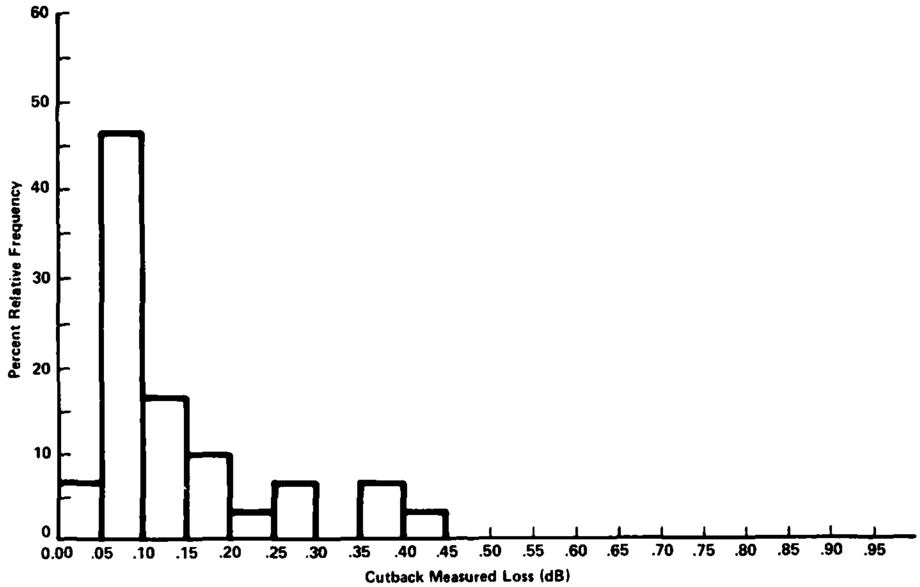


Figure 6 Splice Loss Using the LLM

Figure 7

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THE ROLE OF [illegible]NTERABLE ENCAPSULANTS IN WATERPROOF CLOSURES [illegible]TALLIC TELECOMMUNICATIONS CABLES

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The use of re-enterable urethane encapsulant for the waterproofing of metallic telecommunication cable has been required in the industry for over a decade. However, both petroleum jelly and Flexgel cables have shown oily interfaces when in contact with the current encapsulants, which can potentially lead to water leak paths and subsequent failure of the closure. The need for an encapsulant which eliminates the interfacial oils became apparent.

This paper describes a range of experiments used to determine the parameters that a new encapsulant must satisfy to give enhanced performance in a buried closure system.

Introduction

A major requirement for telecommunication links is a reliable operation for at least 20 years. The reliability of the system can be greatly influenced by water ingress, either down the cable or at a cable splicing point. The splice closure can often be a vulnerable section and the practice of using a re-enterable urethane encapsulant for the waterproofing of metallic telecommunications cable splice closures has been required in the industry for over a decade. The main application being in the area of buried closures which are most susceptible to water entry and migration problems.

The presence of water in a copper system will inevitably lead to a deterioration in transmission properties. The new Bell South specification, which addresses the buried closure system and not just the closure itself, has highlighted several areas where urethane encapsulants currently used by the Bell Operating Company are weak.

Over the past 12 months, several new re-enterable urethane encapsulants have been produced. The discussion will review some of the properties in general and describe the functional testing of these second generation re-enterable urethane encapsulants.

In accessing the properties of a re-enterable encapsulant, a successful candidate should

- Be compatible with the filling compound in the cable,
- Have good penetration of the cable core to ensure blocking,
- Be readily and easily re-entered, and
- Be as craft insensitive as possible.

D-Encapsulant

D-Encapsulant is the most commonly used encapsulant at the present time and has been in use for almost a decade. The encapsulant is prepared by mixing an isocyanate prepolymer with a polyol, and applied to the splice closure by either gravity pouring or by a forced encapsulant system. The latter method has gained a large amount of acceptance within the industry, since good cable core penetration cannot be achieved by gravity poured encapsulation.

The evaluation of splice closures using D-Encapsulant in the Bell South specification showed that water ingress in a splice closure was present when the complete closure was subjected to a temperature excursion of >54°C, and then was immersed in 3 feet of water and/or 8 ft. waterhead applied down the core of the cable for 30 days. Water was detected via measurement of the insulation resistance during applied waterhead and dissection.

When left at ambient temperature or temperatures <54°C, the closure was dry after the normal 8 ft. waterhead. This phenomena was observed irrespective of the type of filling compound used in the cable. Both petroleum jelly and flexgel filled cables showed water ingress down the core at temperatures >54°C.

On re-entering the closures, the encapsulant was not dry but had an oily consistancy. Petroleum jelly filled cable had considerable amounts of oil present. The work of Sabia and Mitchell (Table I[1]) in developing Flexgel showed that petroleum jelly coated conductors have a weak pull out strength when embedded in D-Encapsulant. Flexgel, on the other hand, has a much stronger pull-out force. Flexgel is clearly shown to have some compatibility with D-Encapsulant at room temperature.

Table I[1] (Sabia, Mitchell)

PULL OUT STRENGTH OF INDIVIDUAL CONDUCTORS EMBEDDED IN D-ENCAPSULANTS

Filling Compound	Pull-Out Strength (lbs.) Uncleaned	Cleaned
Flexgel	2.47	2.84
Petroleum	0.27	3.96

Experiments were conducted in which D-Encapsulant was allowed to cure in contact with petroleum jelly and Flexgel. An oily film was very visible in the core of petroleum jelly and traces of oil were found on the case of Flexgel. The differences in pull-out strengths found by Sabia and Mitchell can be explained by the presence of interfacial oily layers, petroleum jelly being the dominant oily interface.

In order to understand the water ingress after a temperature excursion of >54°C, an attempt to measure the pull-out strengths at elevated temperatures (60°C) was carried out. Samples of air core, petroleum jelly, and flexgel coated conductors were embedded in D-Encapsulant in a test tube, allowed to cure, and then placed in an oven at 60°C. After a period of 30 minutes, the conductors coated with filling compound were observed to be "extruding" from the encapsulant, and measurement of the pull-out strength was zero.

The summary of results shown in Table II indicate that although Flexgel has some compatibility at room temperature, elevation of the temperature level leads to a complete loss of adhesion. Further evidence of oily interfaces with petroleum jelly and Flexgel is shown in Table III; measurement of weight gain or loss of the curing encapsulant in direct contact with the filling compound was carried out. Accelerated aging by placing a sample of sured D-Encapsulant in contact with the filling compound for 7 days at 60°C is shown in Table IV.

Table II

PULL-OUT STRENGTHS OF CONDUCTORS IN D-ENCAPSULANT

Filling Compound	Pull-Out Strength (lbs.) 23°C	60°C
Air Core	5.28	3.30
Flexgel	2.64	--
Petroleum Jelly	0.22	--

Table III

% WEIGHT LOSS/GAIN OF D-ENCAPSULANT ON CURING IN CONTACT WITH FILLING COMPOUND AT RT

Filling Compound	% Wt. Gain/Loss	Oily Layer
Petroleum Jelly	-10.4	Yes
Flexgel	- 4.9	Yes

Table IV

% WEIGHT LOSS/GAIN OF CURED D-ENCAPSULANT ON CURING IN CONTACT WITH FILLING COMPOUND (7 Days @ 60°C)

Filling Compound	% Wt. Loss/Gain
Petroleum Jelly	-22.3
Flexgel	- 8.6

Tables III and IV show that D-Encapsulant looses oil when in contact with either petroleum jelly or Flexgel. The generation of oily interfaces, when D-Encapsulant is in contact with a coated conductor, can lead to potential leak paths and allow water ingress from the cable into the splice area.

NEW GENERATION RE-ENTERABLE URETHANE ENCAPSULANTS

Numerous new re-enterable encapsulants have been evaluated in comparison to D-Encapsulant. The initial evaluations centered on

-Good pull-out strength on coated conductors at 60°C, and

-The ability to absorb filling compounds.

Table V summarizes the experimental results for a series [illegible] encapsulants. The results clear[illegible] major enhancement of adhesion [illegible] of the coated conductors. Significant [illegible]pound absorbing properties were also [illegible] of the new generation encapsulants [illegible] out s[illegible]ength at 60°C when compared [illegible]psulant; [illegible] adi[illegible] absorb Flexgel.

When cured in contact with the filling compound, all the new encapsulants absorb both Flexgel and petroleum jelly. When left in contact with cured encapsulant, petroleum jelly is absorbed by one encapsulant (W), however, the other encapsulants show substantial improvement over "D".

The oil *absorbancy increase* by the new encapsulants is reflected in the substantial increase in pull-out strength, especially at high temperatures. In fact, all the new encapsulants have a pull-out strength at 60°C with petroleum jelly, that is higher than D-Encapsulant at 23°c. Many have a pull out strength in petroleum jelly at 60°C approaching that of D-Encapsulant with Flexgel at 23°C. Better adhesion between the conductor and encapsulant can lead to a better performing encapsulant since a potential leak path has been eliminated.

All the encapsulants have superior properties to D-Encapsulant when the oil absorbing properties are evaluated. However, *several other factors are important* in choosing a replacement for D-Encapsulant. Viscosity of the urethane mix prior to curing, and the rate of cure are also are important considerations.

Table V

COMPARATIVE STUDIES OF ENCAPSULANTS

	"D"	W	X	Y	Z
Pull-Out Strength (lbs. @23°C)					
Air Core	5.28	5.72	4.18	1.98	5.06
Flexgel	2.64	8.58	4.84	4.62	8.14
Petroleum Jelly	0.22	4.18	2.86	2.86	4.18
Pull-Out Strength (lbs. @60°C)					
Air Core	3.30	11.20	6.82	5.72	11.22
Flexgel	--	5.28	2.42	3.08	5.50
Petroleum Jelly	--	2.42	0.88	1.54	2.20
% Wt. Loss/Gain of Curing In Contact					
Flexgel	-4.9	+7.0	+4.3	+6.8	+6.4
Petroleum Jelly	-10.4	+0.7	+0.9	+0.8	+1.2
% Wt. Loss/Gain For 7 Days Contact At 60°C					
Flexgel	-8.6	+8.4	+4.5	+6.8	+4.5
Petroleum Jelly	-22.3	+0.4	-6.9	-7.7	-4.5

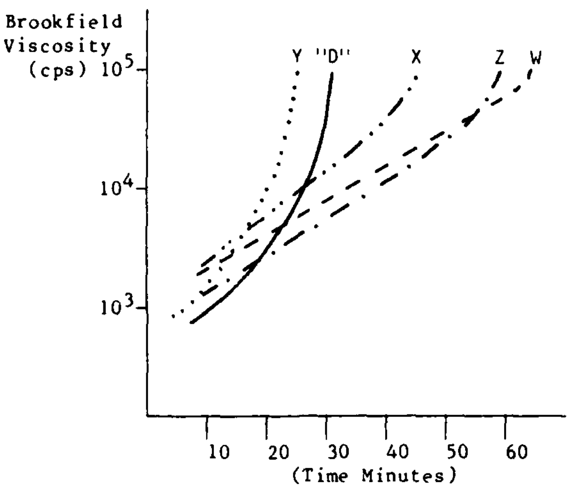
Figure 1 shows the viscosity increase with time for "D" compared to the new generation encapsulants. "D" and Encapsulant Y have a very rapid viscosity increase with time. The other three have a different behavior in that although *the initial viscosity is higher that "D"*, the increase in viscosity is not as rapid as "D". In fact, the viscosity increase profile is much flatter. Encapsulants X, Z, and W have much longer cure times in comparison to "D".

A slow viscosity increase with time is an advantage in using encapsulants in a buried splice closure. In the case of large pair count cables, penetration of the core is difficult. As the viscosity increases, the degree of penetration will decrease. In hot climatic conditions, very rapid curing (i.e. rapid increase in viscosity) will be problematic during installation. The craft person must work rapidly, and any unforseen delay could lead to a mix too

viscous to allow good penetration. Even with a forced encapsulation system which applies pressure to force encapsulant into the core, craft sensitivity can be important.

Figure 1

BROOKFIELD VISCOSITY MEASURED AT RT



The encapsulants with a longer cure time and flatter viscosity profile allow more time for penetration at low viscosities. The craft sensitivity should be greatly reduced, especially in hot climatic conditions.

Functional Testing

The small scale laboratory experiment discussed previously has identified several encapsulants with properties superior to "D", notably, enhanced adhesion and removal of oily interfaces at the conductors. Functional testing of the encapsulants was carried out on

(a) a typical gravity poured closure, and

(b) a heat shringable closure using a forced delivery system.

Gravity Poured Closure

Splices assembled on a non-cleaned, 400 pair, filled cable were immersed in 3 feet of water, and subjected to an 8 ft. waterhead for 30 days. In all cases, the closures failed by having a considerable amount of water present in the closure. The penetration of the core was poor, thereby allowing water ingress.

The sealing areas around the cable/closure also allowed the ingress of water.

Heat Shrinkable Closure With Forced Encapsulant Delivery System

Splices assembled on a non-cleaned, 400 pair, filled cable after immersion and waterhead at the previously mentioned conditions, all passed (i.e. no water present in the closure).

Closures assembled similarly, but cycled from -40°c to +60°C for 15 cycles, and then subjected to immersion and waterhead showed passes in the cases of the Encapsulants W, X, Y, and Z. "D", however, showed the presence of water. On dissection, the absence of oily interface was clear with the new generaton encapsulants; the penetration of the core was good.

The final selection for good replacements for "D" was made by evaluating the re-entry properties of the new encapsulants. All encapsulants had different re-entry characteristics.

"D"	Easy to re-enter. Oily interfaces leave "greasy" connectors. Breaks in lumps.
W	Easy to re-enter. Clean on re-entry. Breaks in lumps. No oily interfaces
X	Very hard to re-enter. Soft and very elastic. Too tacky. No oily interfaces.
Y	Easy to re-enter, but elastic. Clean on re-entry. Breaks in lumps. No oily interfaces.
Z	Easy to re-enter. Clean re-entry. Tends to crumble. No oily interfaces.

Table VI shows the physical properties of the cured encapsulants. The encapsulants with easy re-entry have ultimate elongation of <200%. Y is far too elastic to allow good re-entry; the connectors do not break away cleanly.

Table VI

	T.S. (psi)			U.E. (%)		
	-10°C	25°C	60°C	-10°C	25°C	60°C
"D"	12	13	10	150	130	5[illegible]
W	14	14	10	90	80	40
X	6	8	4	370	390	180
Y	16	12	10	200	130	180
Z	21	15	15	50	50	20

CONCLUSIONS

Laboratory and functional testing have shown that three of the new generation encapsulants are acceptable as replacements for D-Encapsulant. All these show improvement over "D" in terms of removal of oily interfaces when in contact with filled conductors.

The use of a high temperature pull-out strength test is highly indicative of the absorbancy /compatibility of the filling compound and encapsulant.

The new encapsulants will offer a more reliable encapsulated splice closure, and allow a workable system that does not require cleaning of the coated conductors prior to encapsulation.

Acknowledgements

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References

1. Mitchell, D. M. and Sabia, R., Proceeding of the Twenty-Nineth International Wire and Cable Symposium, p. 15, 1980.

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A FORCED ENCAPSULATION SYSTEM FOR SPLICE CLOSURES

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ABSTRACT

A Forced Encapsulation Splicing System, comprised of a new encapsulant and a new closure, has been developed for buried and underground, re-enterable encapsulated splice closures. The encapsulant is forced into the organized splice geometry of the closure by a method that controls both encapsulant pressure and encapsulant volume during cure time. This method assures thorough encapsulation with a minimum volume of encapsulant and locks the closure shell into a strong vessel which compressively reinforces the encapsulant against water ingress and isolates the encapsulated splice from mechanical stresses.

This system will survive known worst case placing and backfilling conditions without additional protection and still provide waterhead resistance in excess of existing requirements. It is constructed with few parts, using traditional methods and tools. It does not require flame or other energy sources and can be installed anywhere cable is placed. The installed product can be quality inspected by non-destructive visual examination.

I. INTRODUCTION

Splice closures have evolved along with cable designs, construction methods and materials. The goal has always been a reliable closure with maximum water resistance at a reasonable cost which can be safely, efficiently and effectively constructed.

Lead sleeves and galvanized cast iron closures containing compressed air protected the pulp and paper insulated cable splices. Later, plastic closures performed the same function for pressurized cable systems. In the mid-1960s, plastic closures filled with hard polyurethane were used for buried splices of plastic insulated conductors in air core cable. In the early 1970s, plastic splice closures with grease encapsulant were introduced for filled cable. During the mid-1970s, a two part polyurethane encapsulant and a plastic shell were developed to protect the larger pair count cables. It should be noted that in the past non-destructive quality inspection has been possible only for air pressurized closures.

This paper describes the forced encapsulation system for re-enterable splices which comprises a new encapsulant and a new closure. Recent studies of closure performance, encapsulation theory, encapsulants and assembly and placement sensitivities guided development of the system and are discussed below.

II. CLOSURE FAILURE MODES

A study of closure performance confirmed the known failure modes and revealed others that had not previously been apparent. These failure modes are directly related to modes of water entry and can result in electrical faults (see Figure 1). A discussion of these modes follows:

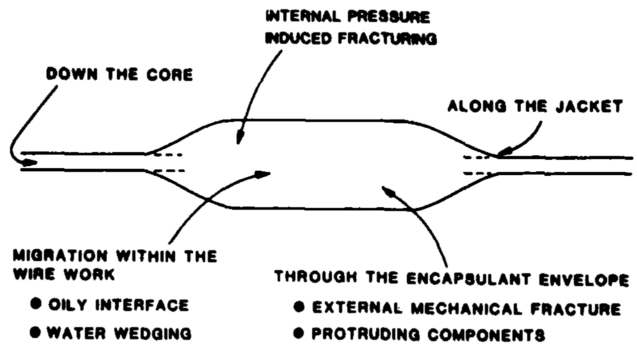

FIGURE 1. MODES OF WATER ENTRY

A. Along Cable Jacket - Water surrounding the closure is forced along the outside of the cable jacket by the pressure of the local water table. Entry is usually through improperly installed or deteriorated blocking collars wrapped or shrunk over a scuffed section of cable jacket.

B. Down Cable Core - Water which has entered a cable at mechanical or lightning damage points may seep along the core and under the sheath

and may penetrate the splice area. Well filled cables are an aid in preventing water entry via this path, but even a trickle will develop a pressure head equal to the elevation difference between the damage point and the splice closure.

C. Through The Encapsulant Envelope - Once inside the closure shell, water can enter the splice through fractures in the encapsulant or along protruding components. Encapsulant fracture may be caused by movement of the unsupported cable relative to the splice or by impact during handling and backfill operations.

D. Within The Wire Work - Once inside the encapsulant envelope, water may migrate within the wire work along any splice components which do not adhere to the encapsulant. Such a condition occurs at an oily interface between conductors and encapsulant that results from improper cleaning of the cable filling compound from the conductors if cleaning is required. As water pressure increases, such an interface may be wedged open causing failure in a short time.

E. Through Pressure Induced Fractures - Water may be wedged into interfaces at pressures as low as 5 psi and fracture some unsupported reenterable encapsulants causing rapid failure of the splice.

III. ENCAPSULATION THEORY[1]

A study was made to determine the factors affecting the penetration of the encapsulant into the splicework that it is designed to protect. The encapsulant is forced by pressure, developed by gravity or other means, into voids in the splice. Depending on the channel structure leading to these voids, air may be trapped or allowed to escape.

Pressure on the encapsulant will reduce the size of bubbles of trapped air. This pressure, P_O, will cause a volume of air, V_{air}, trapped in the fluid encapsulant at an initial pressure, P_{air}, (essentially atmospheric pressure) to be compressed to a volume, V_O, where

$$P_O V_O = P_{air} V_{air} = K \qquad (1)$$

and K is a constant (Boyle's Law).

Pressure will force encapsulant through connecting channels to a void within the cable or splice work of volume, V_{air}, and initial pressure, P_{air}, to achieve the condition described in Equation (1) after a time. This time dependent process has a time constant, τ_t, (see Appendix A):

$$\tau_t = \frac{K\eta}{G\,P_o^2} \qquad (2)$$

where K is the Boyle's Law constant,
η is the viscosity of the encapsulant,
G is a collection of geometrical terms describing the channel and
P_o is the pressure over the encapsulant (plus the small hydrostatic contribution of depth of the encapsulant which is neglected).

Equation 2 clearly indicates that such voids can be filled more quickly by spreading the splice work to open the connecting channels (G), using a low viscosity fluid encapsulant (η) and employing a pressure over the encapsulant (P_O). These three factors in combination with the gel time of the encapsulant (related to τ_t) may be optimized for forcing encapsulant into these voids.

Pressure over the encapsulant has no effect on filling voids which have a number of passages which allow encapsulant to enter and air to escape. Voids of this type are common in splices as long, horizontal air cavities in the wire bundles. The process for filling these voids is also time dependent with a time constant τ_f, (see Appendix B):

$$\tau_f = \frac{V_f \eta}{\sum G_j \rho h_{max}} \qquad (3)$$

where V_f is the volume of the air cavity,
η is the viscosity of the encapsulant,
G_j is the collection of geometrical terms describing the jth inlet channel,
ρ is the density of the encapsulant and
h_{max} is the vertical position of the air outlet port referenced to the lowest inlet port.

Equation 3 shows the means of optimizing the filling of this type of void. The splice work may be spread to increase the cross section and number of connecting channels (G_j) leading to a given volume (V_f). Removing barriers and clutter, e.g., using a tray and a liner with large perforations, have a similar effect (G_j). A low viscosity encapsulant is advantageous (η). Increasing the pressure difference between encapsulant inlet and air outlet ports (ρh_{max}) is helpful in moving air into the fluid encapsulant where it floats away. This may be accomplished by tilting the closure (and voids) or slanting the wire work; however, increasing the pressure on

the encapsulant has no effect on this pressure difference (ρh_{max}). These factors in combination with the gel time for the encapsulant (related to τ_t) may be adjusted for optimum fill, but pressure on the encapsulant does not aid filling this type of void which vents air.

IV. ENCAPSULANT

A study of encapsulants was made to guide the development of the closure system and to develop a formulation with significantly improved water resistance compared to existing encapsulants. The study confirmed that the encapsulant must have increased fracture resistance, be optimized for efficient splice penetration, make intimate contact with cleaned and uncleaned filled cable conductors without forming oily interfaces and meet existing encapsulant criteria. Significantly, viscosity and gel time should be optimized for efficient splice penetration and initial encapsulant setup during the time the craftsperson tends to normal duties. In addition, the fracture resistance must be as large as possible but still allow the encapsulant to be re-entered. Re-entry of test closures illustrated the advantages of a clear view of the splice through a transparent encapsulant and closure liner. Such an encapsulant was developed and is described in the accompanying paper by Chapin and Sabia.[2]

V. *ASSEMBLY AND PLACEMENT STUDY*

A study of the assembly and placement of a closure examined the impact of human interaction on closure reliability. This study was aimed at the elimination of assembly errors and omissions, the avoidance of damage during placement and the assurance of work safety.

The study indicated that successful assembly is achieved by a logical, sequential building-block procedure requiring a minimum of craft decisions, having no opportunities for omissions and providing immediate feedback of proper assembly. Decision-sensitive operations like wrapping tape, building collars or judging encapsulant volume should be avoided. Operations such as wiping, washing, scuffing and installing of loose parts where incorrect procedure or omission could not be observed in the inspection of the completed closure should also be avoided.

Assembly of the ideal closure should be accomplished with a minimum of components. The assembly procedure should automatically establish dimensional and organizational control of the splice, employ traditional methods and indicate successful completion of each assembly step. Various cable sizes and splice combinations should be accommodated without cutting and fitting of parts.

The placement portion of this study, consisting of investigations of common field conditions for buried and underground installations and soil mechanics research (see Appendix C), also showed the impact of human activity on reliability. Closures, which were designed to be encapsulated in place, were being built at the sides of trenches or a convenient location in a manhole and forced into position. Some buried closures were rotated 180° in the horizontal plane before positioning to take up cable slack, thus transmitting stress into the encapsulated wirework. Large rocks were allowed to impact closures during burial. High cable tensile loads were developed in buried closures from the combination of splice pit dimensions, closure support and backfill methods and in underground closures from improper closure support.

To survive these conditions, closures must prevent encapsulant fracture or movement of splice components, as these would lead to water ingress or broken connections. The encapsulated splice must be isolated from mechanical stresses caused by cable twisting, bending and pulling, including impulsive cable tensile loads as great as 250 lbs (see Appendix C). To meet the requirements of some telephone companies, the encapsulated portion must be protected against impact up to 300 in-lbs and compressive loads up to 500 lbs.

Although complete safety cannot be assured, every opportunity to reduce risk was considered. Material selection and methods of construction were dictated by craftsperson safety. Manual tools were selected over power tools with their attendant wires, hoses and tanks. Torches, which could set off gas explosions or ignite flammable materials in the work space, were excluded. Pressure generation by direct application of force on the fluid encapsulant was employed to avoid the risk of compressed gas.

VI. SYSTEM DESCRIPTION

A system, comprising an encapsulant and closure, was designed to meet all existing criteria[3] as well as additional performance requirements developed from these recent studies. The system, shown schematically in Figure 2, employs controlled pressurization to force the encapsulant into an organized splice which is spaced inside a water barrier or bladder sealed to the cables. The pressurized encapsulant contained by the bladder and shell during and after cure is forced against surfaces to which it bonds and seals. The encapsulant is formulated to seal to uncleaned con-

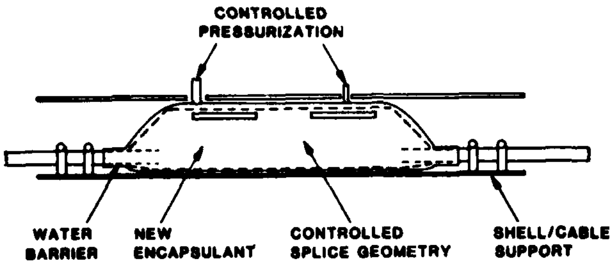

FIGURE 2. FORCED ENCAPSULATION SYSTEM SCHEMATIC

ductors and is fracture resistant. For additional fracture protection, the encapsulated portion of the splice is reinforced by an embedded structure, isolated by the outer shell from mechanical stresses and compressed by this shell. A more detailed examination will now be made of the elements required for this system. Parts and procedures will be discussed for one embodiment in the sequence of assembly as follows:

Step 1. Assemble Splice Organizer

The splice organizer is designed to establish the splice opening, restore sheath continuity, support the splice work, control the splice geometry and reinforce the cured encapsulant. It consists of a tray, a liner and attaching ties mounted on a bond bar to which bonding braids are attached (see Figure 3).

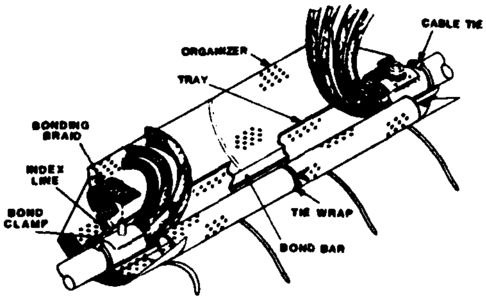

FIGURE 3. SPLICE ORGANIZER

The organizer is prepared for assembly by scrolling and temporarily tying the liner flaps to either side of the tray. The prepared unit is secured to the cables with cable ties and the sheath opening is established by index lines on the tray. Cable sheath continuity is then restored through the bonding braids at either end of the bond bar. Splice support during construction is provided by the tray which is supported on the bottom by the bar and at the sides by the scrolls.

The splice is built in a normal fashion and organized naturally with the connectors at the top. In this position, the connectors have an extra margin of protection should water be forced by high pressure into the wire bundles below.

Upon completion of the splice, the liner is released from the temporary scroll ties, wrapped around the splicework and latched to a predetermined diameter. This diameter fits within the shell but does not compact the splice bundle thus insuring maximum encapsulant penetration. The liner and tray are perforated to aid encapsulant penetration and allow air to escape.

The liner wraps into a cylinder with conical ends to completely envelope the splice work and control the splice geometry (see Figure 4). The cured encapsulant bonds to

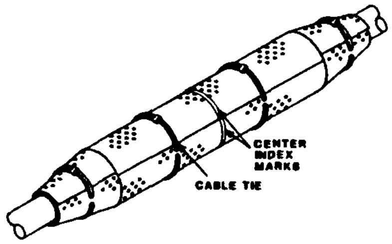

FIGURE 4. ASSEMBLED ORGANIZER

the liner and acts as embedded reinforcement against fracture. A continuous enveloping layer of encapsulant is insured by liner dimples which space the lined splice array from surrounding walls. This geometry allows thorough encapsulation with a minimum volume of encapsulant.

To facilitate re-entry the liner and encapsulant are transparent. This transparency allows a clear view of the splicework to guide re-entry and rapid location of the liner edges which are color marked for this purpose. The overlapped edge is lifted to peel the liner and outer layer of encapsulant and to access the splice work.

All parts necessary to assemble the organizer over the splice are included as an integral part of the unit. Complete and proper assembly is indicated by all cable ties being latched and pulled to a stopped position.

Step 2. Seal Bladder

The bladder serves both as a containment for the fluid encapsulant during the forced encapsulation process and as a water barrier for the completed closure. It may also be used for temporary protection of incomplete splices. The bladder is a tough elastomeric sheet with two spouts and a paper protected mastic around its perimeter (see Figure 5).

The bladder surrounds the splice and is

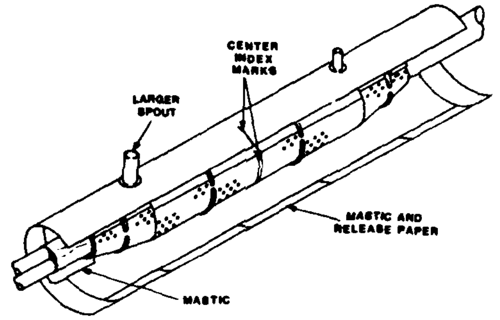

FIGURE 5. BLADDER

sealed to itself and to the cables by the mastic. The protective release paper is removed as sealing progresses. The mastic is formulated to stick to cable sheath without scuffing. An extra strip of mastic is supplied to build a seal around branch cables before the bladder is placed. A cable tie and vinyl tape reinforce each seal to the cables (see Figure 6). Later,

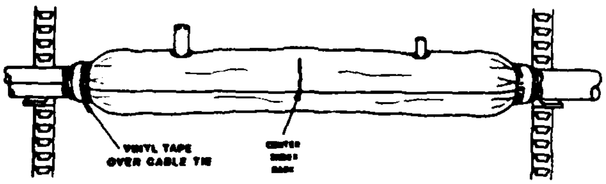

FIGURE 6. ASSEMBLED BLADDER

the splice is filled and pressurized with encapsulant through the larger of the two spouts while air is vented through the smaller spout.

The bladder alone will not hold pressurized encapsulant since the elastomeric material will stretch and the mastic seams will peel. Therefore it is contained in a vessel formed by the outer shell and two end supports.

Step 3. <u>Install End Supports</u>

An end support is wrapped over each end of the bladder to form a cone which axially supports the pressurized bladder (see Figure 7). Each support is a strong,

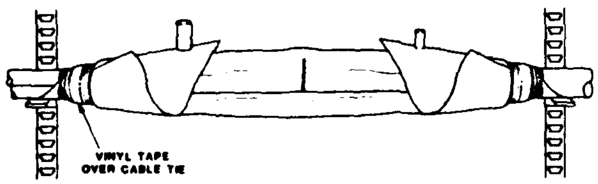

FIGURE 7. END SUPPORTS

shaped, fabric sheet and is held in position by a cable tie and vinyl tape so that the flared edges of the cone can be forced by the pressurized bladder to couple frictionally to the outer shell.

Step 4. <u>Mount Outer Shell</u>

The outer shell radially supports the pressurized bladder, isolates the encapsulated splice from mechanical stress and compressively reinforces the cured encapsulant. It is a rugged, cylindrical, plastic tube split longitudinally into upper and lower shells which lock together (see Figure 8).

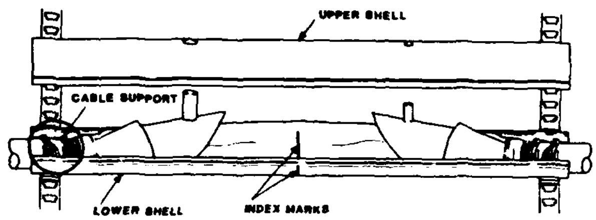

FIGURE 8. OUTER SHELL

The lower shell mounts under the splice by unique cable clamps built into each end of the shell. These clamps fix the cables firmly to the shell and prevent movement in all directions. The upper shell with holes for the bladder spouts is joined to the lower shell by sliding clamps along each joint.

Under the action of the pressurized encapsulant, the shell halves lock into a rigid cylinder to which the cables have been firmly fixed external to the encapsulated portion of the splice. This isolates the encapsulated portion from stresses due to cable twisting, bending or pulling thereby preventing encapsulant fracture. The tough shell, now radially reinforced by the pressurized bladder, protects the splice against encapsulant fracture from impact or compressive loads.

The outer shell, end supports and bladder contain the pressurized encapsulant. Pressurization forces the fluid encapsulant against surfaces to which it bonds or seals. The shell continues to compressively load the encapsulant after curing to hold the bonds and seals against high water heads thereby preventing water wedging and pressure induced fracturing of the encapsulant.

Step 5. <u>Force Encapsulant</u>

After the organizer, bladder, end supports and shell are installed, forced encapsulation of the assembled closure can begin (see Figure 9). The encapsulant is mixed and poured into the closure through the

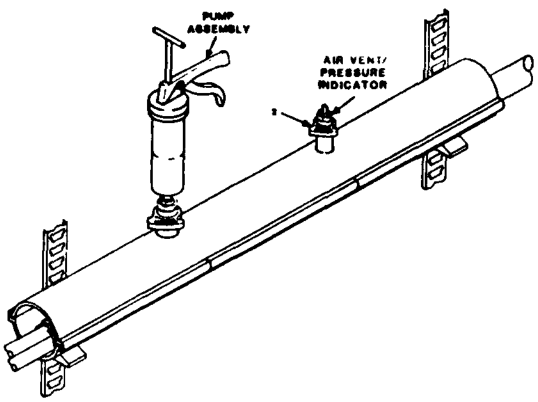

FIGURE 9. PUMPING ENCAPSULANT

large spout until encapsulant appears in the small spout. A check valve is then inserted into the larger spout and an air vent/pressure indicator into the smaller spout. A cartridge gun is connected to the check valve, filled with encapsulant and used to force encapsulant into the closure until the pressure indicator shows 15-18 psi.

During pumping, air is automatically vented through the air vent/pressure indicator which passes air but blocks encapsulant. This minimizes air voids which are potential paths for water ingress and spoil the compressive reinforcement of the cured encapsulant by the shell.

After pumping, the craftsperson periodically checks the pressure indicator while tending to normal cleanup duties. Encapsulant is pumped as needed to maintain pressure. When the pressure has stabilized, the pump is removed and a protective cap is placed over the air vent/pressure indicator.

Control of encapsulant pressure and volume during cure is vital. Encapsulant is forced out of the closure and into cable fill defects causing a reduction of the pressure and its encapsulation advantages (see Equation 2). Adding encapsulant restores the pressure to the desired level and insures a sufficient volume to protect the splice.

Step 6. Inspect Completed Closure

It is a simple matter for the craftsperson to inspect the completed closure during or following the forced encapsulation. The inspection consists of a visual examination of the pressure indicator for proper reading and the open closure ends for leaks.

Since the splice geometry has been established within the bladder, this simple inspection checks the proper assembly of remaining components and provides a go/no go indication of successful splice closure construction and encapsulation to the craft. This same inspection can be performed by quality inspectors at anytime in the future. After inspection, the open closure ends are closed with plastic foam blocks to keep out dirt and debris.

VII. WATERHEAD RESISTANCE OF COMPLETED SYSTEM

Forced encapsulated system closures as described above were assembled and each was subjected to the sequence of Appendix D tests concluding with separate water immersion and sheath injection waterhead tests of 3 feet and 8 feet respectively which exceeds present requirements.[3] Present requirements conduct the 3 foot immersion and 8 foot sheath injected waterheads simultaneously which yields an effective sheath injected waterhead of only 5 feet for many closure systems. The results verified that this closure system passes the more severe tests and demonstrated that waterhead resistance improvements are possible with compressive reinforcement of the encapsulant. In laboratory tests, closures have routinely resisted waterheads of 16 feet and have been built to resist 23 feet for more than 30 days.

Gravity filled encapsulated closures of the past would hold back a 5 foot head (sheath injected waterhead of 8 feet less a water immersion head of 3 feet), if constructed carefully and handled properly. The new pressurized system automatically guarantees the proper assembly and handling protection and employs the new encapsulant[2] so that a separately applied 8 foot sheath injected waterhead resistance is assured.

The total waterhead resistance for the system is achieved by both the new encapsulant and the pressure maintained on the encapsulant and is empirically defined as:

$$\text{Waterhead Resistance} \approx 8 \text{ feet} + \text{Encapsulant Pressure} \quad (4)$$

This relationship is depicted in Figure 10 and has been verified over the range of 0 to 23 feet.

For the water immersion case, the surrounding water contributes to encapsulant pressure by loading the void free encapsulant sealed inside the water barrier (bladder). This contribution increases with immersion depth so the present 3 foot immersion criteria is no challenge.

For the sheath injection case, water forced through a cable does not significantly contribute to the encapsulant pressure and is blocked by the encapsulant as pressurized by the closure.

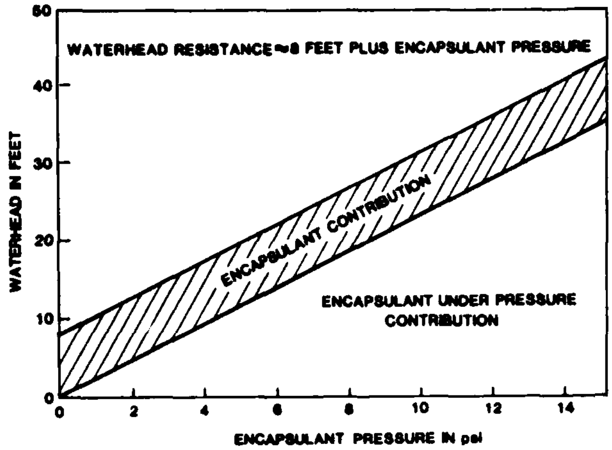

FIGURE 10. WATERHEAD RESISTANCE PLOT

VIII. Performance and Advantages

This closure system meets or exceeds all existing requirements. It will withstand compressive loads of 500 lbs., impact of 300 in-lb and cable tensile loads of 150 lbs. per inch of cable diameter up to 250 lbs. and still survive a separately applied sheath injected waterhead of 8' and more. This data indicates that the closure system will survive difficult placing and backfilling conditions without additional protection and can even be spliced above ground and buried later.

The system has been successfully installed in buried and underground plant and can be used if desired in aerial applications. Less than ten closure sizes will accommodate all splice combinations of all cable sizes with no cutting or fitting of parts. Since installation requires no external power sources such as compressed air, electricity or flame, the system may be safely installed in manholes, oil refineries or chemical plants and placed jointly with natural gas lines.

The system is constructed from a few major parts using traditional methods. No concealed wrappings, cable collar build up, cable sheath scuffing or conductor cleaning are required. Splice dimensions and organization occur naturally and automatically without craft decision.

A non-destructive visual examination of a completed splice and its indicated pressure shows whether it was constructed satisfactorily. This provides a go/no go indication to the craft so corrective action can be taken before leaving the worksite. It allows management to perform a non-destructive quality inspection at any time in the future.

IX. SUMMARY

A closure/encapsulant system has been designed which meets or exceeds all existing requirements. The robustness of the new closure enables it to survive the rigors of handling and backfilling during the placement process and still provide water resistance superior to all previous design concepts. Proper construction is assured by a non-destructive, visual quality inspection that can be performed during and after assembly. The closure system has been tested in buried and underground installations and has demonstrated performance superior to other closure designs. All of this is achieved in a reliable system at a reasonable cost which can be safely and efficiently constructed.

X. ACKNOWLEDGEMENTS

The work described in this paper represents the efforts of many people. Acknowledgement is made of the contributions of the following:

AT&T Bell Laboratories:

Cable and Wire Group
Connector Systems Group
Material and Chemistry Group
Sheath Joining Group
Operation and Training Group

AT&T Technologies:

Product Engineering Control Center
Product Planning
Omaha Manufacturing Engineering

In addition, the cooperation of several Bell Operating Companies that agreed to try the system in actual applications is appreciated.

REFERENCES

1. W. C. Reed, "A Short Term Water Resistance Test for Filled Service Wire," 28th International Wire and Cable Symposium, November 1979.

2. J. T. Chapin and R. Sabia, "Laboratory Performance Tests and Criteria for Re-enterable Encapsulants," Paper to be presented at the 34th International Wire and Cable Symposium, November 1985.

3. Bell System Technical Reference, PUB55004, Issue 1, "Waterproof Splice Closures," 1981.

APPENDIX A
VOIDS WHICH TRAP AIR[1]

Consider a void of volume, V, within a cable, connector or splice work which has access to fluid splice encapsulant through a small passage (see Figure 1a). At some time the cavity will contain some air, V_{air}, and some encapsulant, V_{enc}, so that

$$V = V_{air} + V_{enc} \tag{1}$$

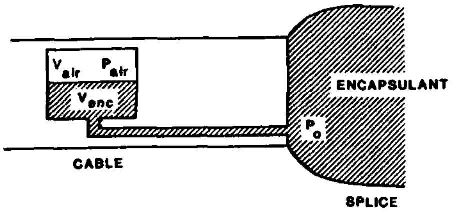

Figure 1a. Encapsulant Flow Into a Cable Void Which Traps Air.

Pressure on the splice encapsulant at the passage entry, P_o, forces encapsulant into the cavity and compresses the trapped air to a pressure P_{air}. Encapsulant moves into the cavity until $P_{air} = P_o$ (neglecting hydrostatic pressure contributions of the encapsulant) at which time $V_{air} = V_o$. Assuming the compression to be isothermal

$$P_{air}\, V_{air} = P_o\, V_o = K \quad \text{(Boyle's Law)} \tag{2}$$

The volume rate of flow, Q, of encapsulant into the cavity is determined by the pressure difference, $P_o - P_{air}$, the viscosity of the encapsulant, η, and the geometry of the passage, G. From Poiseuille's Law, Q may be expressed as

$$Q = \frac{G\left(P_o - P_{air}\right)}{\eta}\,. \tag{3}$$

G for laminar flow through a cylindrical passage of radius, R, and length, L, is

$$G = \frac{\pi}{8}\frac{R^4}{L} \tag{4}$$

but such simple geometry is not to be expected for passages in splices and cables. Fortunately G is considered constant in the following mathematical development and comparisons so that exact geometry need not be known.

By definition Q is

$$Q = \frac{dV_{enc}}{dt} \tag{5}$$

Combining Equations (2), (3), and (5), the volume rate of flow may be expressed as

$$\frac{dV_{enc}}{dt} = \frac{G}{\eta}\left(P_o - \frac{P_o\, V_o}{V_{air}}\right) \tag{6}$$

From Equation (1), Equation (6) may be rewritten as

$$\frac{dV_{enc}}{dt} = \frac{G\, P_o}{\eta}\,\frac{V-V_{enc}-V_o}{V-V_{enc}} \tag{7}$$

and

$$\frac{V-V_{enc}}{V-V_{enc}-V_o}\, dV_{enc} = \frac{G\, P_o}{\eta}\, dt \tag{8}$$

To determine the volume of encapsulant, V_{enc}, in the cavity at any time, t, Equation (8) is integrated.

$$\int_0^{V_{enc}} \frac{V-V_{enc}}{V-V_{enc}-V_o}\, dV_{enc} = \int_0^{t} \frac{G\, P_o}{\eta}\, dt \tag{9}$$

which yields

$$\ln\left|V_{enc}-V-V_o\right| - \ln\left| -\left(V-V_o\right)\right| = -\frac{G\, P_o}{\eta\, V_o}\, t + \frac{V_{enc}}{V_o} \tag{10}$$

Equation (10) is simplified by substituting an expression for the maximum volume of encapsulant which may enter the cavity at P_o, $V_{enc\ max}$,

$$V_{enc\ max} = V - V_o \tag{11}$$

and the constant from Boyle's Law

$$K = P_o\, V_o \tag{12}$$

With these substitutions, Equation (10) may be written in exponential form as

$$\frac{V_{enc\ max} - V_{enc}}{V_{enc\ max}}\, e^{\frac{-V_{enc}}{V_o}} = e^{\frac{-G\, P_o^2}{K\eta}\, t} \tag{13}$$

The right hand term has the form e^{-t/τ_t} where τ_t is the time constant. Thus, the time constant for the flow of encapsulant into a cavity in a splice or cable which traps air is

$$\tau_t = \frac{K\eta}{G\, P_o^2}$$

APPENDIX B
VOIDS WHICH DO NOT TRAP AIR[1]

Consider a void of volume, V_f, within a bundle of wires which is accessed by a number of passages such that air may escape. (See Figure 1b.)

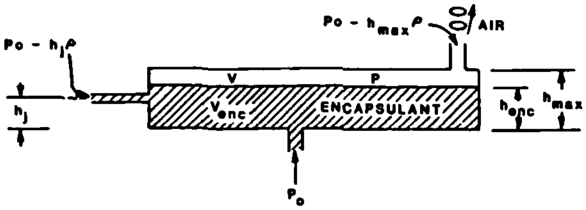

Figure 1b. Encapsulant Flow Into a Wire Bundle Void Which Does Not Trap Air.

The volume rate of flow, Q, of the water into this cavity is the sum of the volume rate of flow for each passage, Q_j,

$$Q = \sum_{j=1}^{n} Q_j \tag{1}$$

where n is the number of passages.

The volume rate of flow for each passage is now expressed as

$$Q_j = \frac{G_j \left(P_{oj} - P - h_{enc}\rho\right)}{\eta} \tag{2}$$

where h_{enc} is the hydrostatic pressure of the encapsulant within the cavity. h_{enc} is the vertical height of the encapsulant within the cavity referenced to $h_j = 0$, ρ is the density of the encapsulant and η is the viscosity of the encapsulant.

P_{oj} is the sum of the outside pressure and the hydrostatic pressure of the encapsulant

$$P_{oj} = P_o - h_j\rho \tag{3}$$

where h_j is the vertical height of an entrance port referenced to $h_j = 0$.

Since air escapes the cavity from some escape port, the pressure of the air in the void automatically adjusts to the pressure of the encapsulant at the escape port.

$$P = P_o - h_{max}\,\rho \tag{4}$$

where h_{max} is the vertical position of the escape port referenced to $h_j = 0$.

Combining Equations (2), (3), and (4), the volume rate of flow for each passage is

$$Q_j = \frac{G_j \left(h_{max} - h_j - h_{enc}\right)\rho}{\eta} \tag{5}$$

and the total volume rate of flow Q is

$$\frac{dV_{enc}}{dt} = \sum_{j=1}^{n} \frac{G_j \left(h_{max} - h_j - h_{enc}\right)\rho}{\eta} \tag{6}$$

h_{enc} may be approximated in terms of V_{enc} as

$$h_{enc} = \frac{V_{enc}}{A} \tag{7}$$

where A is the cross sectional area of the cavity.

Equation (6) can now be solved to determine the volume of encapsulant, V_{enc}, in the cavity at any time, t. The solution is

$$\int_0^{V_{enc}} \frac{dV_{enc}}{\sum \frac{G_j \left(h_{max} - h_j\right)\rho}{\eta} - \sum \frac{G_j\,\rho\,V_{enc}}{\eta\,A}} = \int_0^t dt \tag{8}$$

which simplifies to

$$\frac{\sum G_j \left(h_{max} - h_j\right) - \sum G_j \frac{V_{enc}}{A}}{\sum G_j \left(h_{max} - h_j\right)} \quad e^{-\sum \frac{G_j\rho}{\eta A} t} \tag{9}$$

Thus the time constant for filling the cavity with encapsulant, τ_f, is

$$\tau_f = \frac{A\eta}{\sum G_j\rho} \tag{10}$$

or, since Ah_{max} is the volume of the cavity V_f,

$$\tau = \frac{[illegible]}{G_j [illegible]} \tag{11}$$

APPENDIX C
SOIL MECHANICS STUDY

A study was made to determine the kind of treatment that a closure is subjected to during the process of placement and burial. This study confirmed that some of the existing requirements for buried closures were realistic. However, cable tensile loads during fill were found to be more severe than anticipated in existing requirements. A single size closure was used in the evaluation.

To accurately evaluate the conditions involved, a simulated pit was constructed. This pit was instrumented to monitor the tensile loads applied to the closure during the backfill operation. This pit is illustrated in Figure 1c. A load cell was placed on the cable to measure the loads during backfill. The tensile load measurements obtained are shown in Figure 2c. The chart indicates a maximum peak load of 300 pounds. When the preload of 50 pounds is subtracted, then 250 pounds tensile load is applied to the cable when the first load of dirt is dumped on the closure. Subsequent loads are less severe. Loading similar to that obtained by tamping and rolling with a backhoe are also shown.

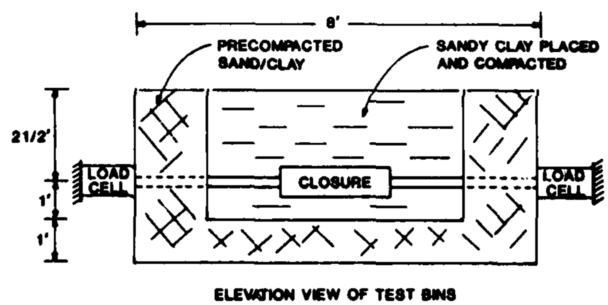

FIGURE 1c. SOIL MECHANICS STUDY

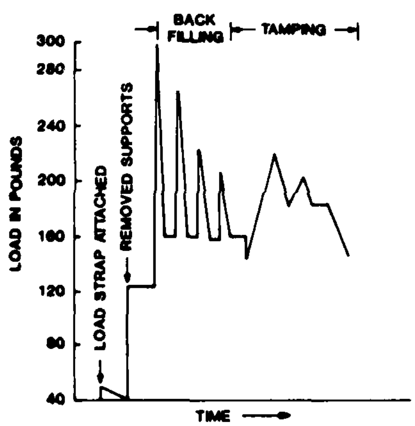

FIGURE 2c. TENSILE LOAD DURING BACKFILL

APPENDIX D
CLOSURE TESTS

Forced encapsulation system splice closures were sequentially subjected to compression, impact, cable pull out and water tests to verify that end use and long term reliability requirements were met. These tests are described below.

A. Compression Test

A 500 pound uniformly distributed load is applied for five hours at temperatures of 0°F (-18°C) and 100°F (38°C). The deformation shall be less than 10% of the original closure diameter. This test is illustrated in Figure 1d.

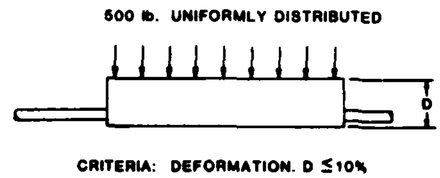

FIGURE 1d. COMPRESSION TEST

B. Impact Test

The closure is subjected to an impact of 300 inch pounds at temperatures of 0°F (-18°C) and 100°F (38°C). Neither the closure shell nor the encapsulant shall be damaged. This test is illustrated in Figure 2d.

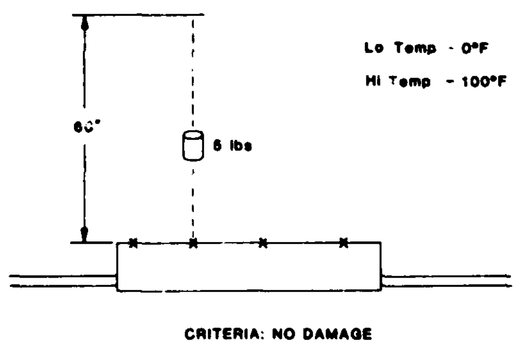

FIGURE 2d. IMPACT TEST

C. Cable Pullout Test

A dead weight tensile load is applied to each cable entering the restrained closure. The load applied to each cable is 150 pounds per inch of cable diameter not to exceed 250 pounds. The load is applied for five hours. The displacement of the cable relative to the closure shall be less than 1/8 inch. The test arrangement used is illustrated in Figure 3d.

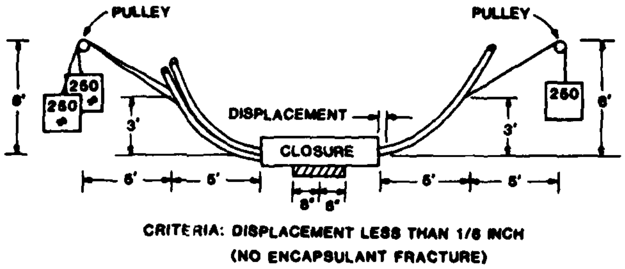

FIGURE 3d. CABLE PULLOUT TEST

D. Water Tests

The existing water resistance test[3] requires simultaneous immersion of a closure in three feet of water and sheath injection of an eight foot waterhead. Since these waterheads counteract each other for some closures, an effective sheath injected waterhead of only 5' is possible. For this reason, these tests are done separately. The closure is submerged in three feet of water as shown in Figure 4d for 30 days. After this time there shall be no water inside the splice and all pairs shall maintain an insulation resistance (IR) of greater than 10^9 ohms.

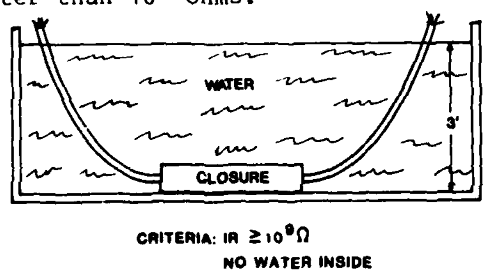

FIGURE 4d. WATER IMMERSION TEST

The closure is then subjected to a waterhead applied to the cable core through a prepared opening in the sheath. The waterhead is applied for 30 days. An insulation resistance greater than 10^9 ohms shall be maintained with no water in the splice. The test is illustrated in Figure 5d.

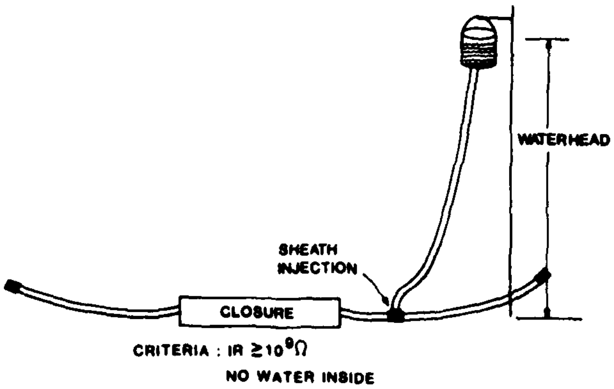

FIGURE 5d. SHEATH INJECTION WATERHEAD TEST

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LABORATORY PERFORMANCE TESTS AND CRITERIA FOR REENTERABLE ENCAPSULANTS

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Abstract

Encapsulated splice closures are widely used to protect a splice from water entry. In this paper, failure modes are briefly reviewed. Assuming water entry down the cable core, closure failures due to oily interfaces and wedging are identified as being strongly encapsulant dependent. A splice simulation test has been developed which assumes that a water head acts directly on the splice. In this worst case situation, variables such as cable filling compounds, splice wire work density, connectors, water head, and encapsulant gel time and viscosity are investigated. Data are presented on how these factors influence performance. The result is that a new encapsulant has been formulated which exhibits significant improvements in performance over other commercial encapsulants.

Introduction

The goal of a reliable, low maintenance telephone plant led to the development of filled cables in the late 1960's.[1,2] This development was followed by the introduction of filled connectors, filled service wire and filled splice closures. The weak link in this filled system has been the splice closure[3] as it is highly vulnerable to water ingress due to system incompatibilities and/or improper installation procedures under field conditions.

A splice closure is intended to restore the cable integrity by acting as an extension of the cable sheath. A brief historical review of splice closure development is presented in the accompanying paper at this symposium by Angel, Mullin and Reed.[4] The preferred closure filling compound is a two part oil extended reenterable polyurethane, commonly referred to as D encapsulant,[3,5,6] although high density oils, soft greases, thermoplastic mastics and hydrophobic powders have been used.

In this paper, filled closure failure modes[4] will be reviewed. Then, criteria for the development of an improved, two part encapsulant will be presented. Standard test data will be listed for a new encapsulant that meets these criteria. The paper will then focus on specific compatibility tests and introduce new performance tests. The data will show that the new encapsulant is a very important step towards improving the reliability of new closure designs such as the one described by Angel, Mullin and Reed.[4]

Other papers at this and earlier symposia attest to the crucial importance of encapsulants and closures to the cable plant. A theme emerges: the encapsulant and closure system must work together to restore the electrical and mechanical properties of the cable.[6]

Closure Failure Modes

Angel, Mullin, and Reed[4] report closure failure modes that are directly related to water entry and which usually result in electrical faults. These are summarized in Figure 1. It is difficult to separate these failure modes as being primarily closure design dependent or encapsulant dependent. The interdependence of these two factors dictate that encapsulants be developed using closure test data. As closure tests require significant lead time and are very expensive, it was necessary to develop the closure simulation test described below.

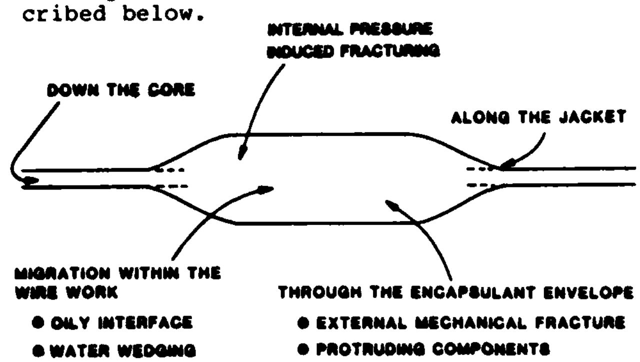


FIGURE 1. MODES OF WATER ENTRY

Criteria For An Improved Encapsulant Formulation

After examining failure modes, assuming a poorly filled cable core which offers little or no resistance to water entry into the splice area, and characterizing properties of existing encapsulants, the properties of materials required for an improved encapsulant were identified.

Thus, improved compatibility of the encapsulant with cable and closure components (filling and sealing compounds, mastics, tapes, etc.) became a goal. Another goal was to increase the pot life (the time in which the viscosity increases above a critical value, e.g., too viscous to flow readily) of the encapsulant to insure complete penetration of the splice bundle regardless of the field temperature and degree of splice congestiveness. Lastly, the fracture strength of the encapsulant was identified for improvement. The first goal is critical to any successful closure design. The goals of complete penetration and fracture toughness are enhanced by closure design and are covered also in the accompanying paper by Angel, Mullin and Reed.[4] These goals were accomplished while maintaining or exceeding the proven, satisfactory properties of D encapsulant[3,5] such as:

1) safety

2) shelf life

3) reenterability

4) stress cracking effects on plastics

5) hydrolytic stability

Existing Encapsulant and Performance Specifications

Bell System Technical Reference on "Waterproof Splice Closures", PUB 55004, and Bellcore CAO8735 D Encapsulant Specification address compositional and cure properties of a two part, polyurethane encapsulant, compatibility of the encapsulant with closure components, and full scale performance testing of filled closures. In our work, we emphasized testing for compatibility with closure materials while meeting or exceeding other encapsulant properties. The full scale closure tests were replaced by simulated splice tests in which the ability of an encapsulant to maintain high insulation resistance of spliced conductors in the presence of external water pressure is measured.

Materials Properties

Materials requirements from CAO8735 are listed in Appendix A, along with data obtained on an encapsulant developed as a result of this work. Some CAO requirements, such as elongation, are purposely broad to allow for innovation in encapsulant development. Other requirements, such as hydrolytic stability, are necessarily restrictive. The new encapsulant meets these requirements and in most cases exceeds them. An increase in component viscosity at 40°F and gel time were necessary to attain improved closure performance.

Compatibility Properties

Out of the materials requirements in Appendix A, selected compatibility requirements will be discussed in the following sections. Specifically, compatibility of the encapsulant with cable filling compounds and connectors will be discussed. Compatibility with sealing tapes, mastics, liners, etc. has also been addressed but will not be discussed since these are more closure-design specific. It is sufficient to state that compatible closure materials are readily selected once the compatibility of the encapsulant with cable filling compounds is established.

Conductor Pullout Force

The compatibility of an encapsulant with cable filling compounds is highly desirable since cleaning insulated conductors under field conditions cannot be assured. The conductor pullout test is a quantitative measure of the interaction between the encapsulant and insulated conductors in the presence of cable filling compounds. The preparation and testing of samples is described in CAO8735. In our tests, 22 AWG conductors from aircore and FLEXGEL† and petrolatum filled cables[7,8] were potted in the encapsulant and, after the encapsulant had cured, the force to pull out the insulated conductor was measured. The polyurethane formulation and the gel time of the encapsulant were varied. For the formulations in Table I, there is a good relationship between polyurethane content and conductor pullout force with aircore and FLEXGEL coated conductors. Petrolatum coated conductors show less of a dependence on polyurethane content. Extending the gel time as in Table II did not increase the conductor pullout force. A weak relationship is shown in Table II between the pullout force and tear strength (a measure of encapsulant reenterability). Thus, the data show that it is

†A trademark of AT&T Technologies.

possible to improve the compatibility between an encapsulant and FLEXGEL and petrolatum filling compounds without degrading reenterability.

Although a difference in pullout force is apparent in Table II between FLEXGEL and petrolatum coated conductors, dissection of D1000 encapsulated closures show that FLEXGEL and petrolatum coated conductors are absolutely free of oil syneresis, indicative of excellent compatibility. However, it is important to note that the pullout force does not necessarily provide insight into the performance of the encapsulant, for example, where compacted wire bundles exist. In this area, encapsulant penetration is dependent on the closure design.

TABLE I

Conductor Pullout Force[a] as a Function of Encapsulant Polyurethane Content

% Polyurethane[b]	Insulated Conductor Coating: Aircore	Petrolatum	FLEXGEL
	Pullout Force, lbs		
30	8.4	2.9	5.1
35	11.0	3.3	6.2
40	13.0	3.1	11.0

[a]Test based on CA08735.

[b]The encapsulant components are the same, only the polyurethane content is varied. The balance is composed of extender oils and/or compatibilizers.

TABLE II

Conductor Pullout Data as a Function of Gel Time

Encapsulant	Gel Time	Insulated Conductor Coating: Aircore	PJ	FLEXGEL	Encapsulant Tear Strength,[e] lbs/in
		Pullout Force, lb			
D[a]	30 min.	7.5	0.4	2.4	3.2
D[b]	17 hrs.	7.1	0.7	2.4	-
D1000[c]	55 min.	13.0	3.1	11.0	4.2
D1[d]	17 hrs.	13.0	2.4	10.1	-

[a]This material is commercially available as D encapsulant.

[b]This material is an uncatalyzed version of D encapsulant.

[c]The properties of this encapsulant are listed in Appendix A.

[d]This material is an uncatalyzed version of D1000.

[e]CA08735.

Stress Cracking Activity

The stress cracking activity of encapsulants is important. Polycarbonate, used in connector designs, is sensitive to stress cracking by esters commonly used in encapsulants. Other closure materials are more forgiving in contact with encapsulants and will not be discussed. The standard method for determining the stress cracking resistance of polycarbonate to encapsulants is described in CA08735. The test involves encapsulation of annealed, injection molded polycarbonate bars stressed to 0.75% strain using a three point fixture. After 30 days at room temperature, no cracks or crazes of the bars are allowed. The assumption in this test is that a good connector design will stress polycarbonate at lower strain levels. The test is of greater benefit to connector designers than to connector users who during closure reentry apply high pull forces to wires spliced into connectors as well as high flexure forces directly to the connectors. Thus, in the current effort, in addition to the bar test, existing end-product connector tests were modifed to determine the degradation if any, of aged, encapsulated modular connectors.

Using modular connectors, spliced with 19 AWG insulated DEPIC conductors, single insulated conductors are pulled out per a modification of the procedure in AT&T's document "Product Criteria for Communications Cable Wire Joining Systems". The force to pull conductors out of the connectors was measured with a tensile testing machine at 2 in/min. at room temperature after 0, 15 and 31 days for specimens encapsulated and aged at room temperature and at 40 and 60°C. Modular connectors manufactured by AT&T Technologies and coded 710 SB1-25 were used. Data for D encapsulant, D1000 encapsulant and a nonencapsulated control are reported in Table III. Theoretically, values corresponding to the strength at break for insulated 19 AWG wire (37.5 lbs) would indicate no degradation of the connectors. Since the wires broke in our tests, rather than pulling out, encapsulation does not significantly affect the strength of the wire joint.

TABLE III

Conductor Pullout Data for Encapsulated, 25 Pair Modular Connectors[a]

	Aging Time, Days	Pullout Force, lbs[b,c] 23°C	40°C	60°C
Control (not encapsulated)	0	37.5	--	--
	15	37.5	37.5	37.5
	31	37.5	37.5	37.5
D Encapsulant	15	35.3	35.3	35.3
	31	35.3	35.3	35.3
D1000 Encapsulant	15	35.3	37.5	37.5
	31	35.3	37.5	35.3

[a]AT&T Technologies, 710 SB1-25 modular connector.

[b]Average of 4 samples.

[c]The theoretical value should be the tensile force at break for the insulated wire, 37.5 lb.

The other test, also conducted to failure, is a flexure test following the procedure outlined in ASTM D 790. The connectors were prepared and tested following the procedure and schedule outlined above and tested on a tensile machine at a crosshead speed of 2 in/ min. The data in Table IV show a reduction in the flexure force on aging at 60°C for connectors encapsulated with D and D1000 encapsulant. However, the residual flexure force is sufficient to allow reentry of encapsulated splices.

TABLE IV

Flexure Force to Failure of Encapsulated 25 Pair Modular Connector[a] After Aging at Various Temperatures

	Aging Time, Days	Breaking Force, lbs[b] 23°C	40°C	60°C
Control	0	136	--	--
(not encapsulated)	15	148	139	130
	31	130	130	119
D Encapsulant	15	125	112	92
	31	121	123	84
D1000 Encapsulant	15	141	123	70
	31	125	108	75

[a]AT&T Technologies, 710 SB1-25 modular connector.

[b]Average of 2 samples.

Splice Simulation Test (SST)

Until now, the only method for evaluating encapsulant performance in a closure was to construct and test full-scale splices. Although valuable information regarding the electrical and mechanical performance of the encapsulant/closure system can be obtained in these tests, the number of experimental variables such as cable pair size, cable core preparation, splicing methods, closure construction methods, etc. make the procedure labor and time intensive - not suited for encapsulant development. To reduce the number of variables and the time required to obtain relevant data, a splice simulation test was devised.

With reference to Figure 1, it was decided that the simulation test would address the more difficult water entry problems, i.e., down the core and within the wire work due to oily interfaces and wedging, leading to insulation resistance failure and to encapsulant fracture at high water heads. The other modes, which are strongly coupled to closure design and are more easily blocked, were not simulated.

Water entry along the core assumes a poorly filled core and was simulated by using wire units pulled out of standard manufacture cables. An oily interface was made probable by not cleaning the insulated conductors. The conditions for wedging of water along the wire work were established by ensuring that the water head on the splice was not restricted and placing it within one inch of the modular splice connector.

Details regarding the materials and construction of SST units are included in Attachment B and in Figures 2 and 3. Briefly, the test cell contains a spliced 25 pair modular connector. The "splice" is surrounded by a liner and secured with cable ties. The splice assembly, along with a ground wire is placed inside a 2" diameter Plexiglas tube with conductors projecting out both ends (see Figure 2). The encapsulant is poured into the "splice" with the tube positioned vertically. Time is allowed for encapsulant to cure (2-3 days). Then, a cable pressure cap with a valve assembly is secured to one end of the test cell in order to apply a water head.

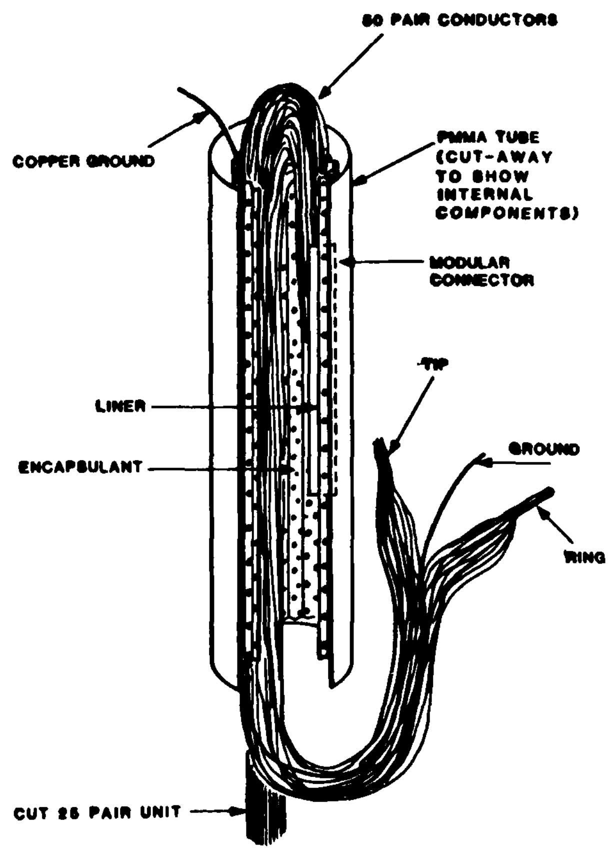


FIGURE 2. ENCAPSULANT TEST CELL

Finally, the SST is attached to a manifold system where water pressure is applied (see Figure 3).

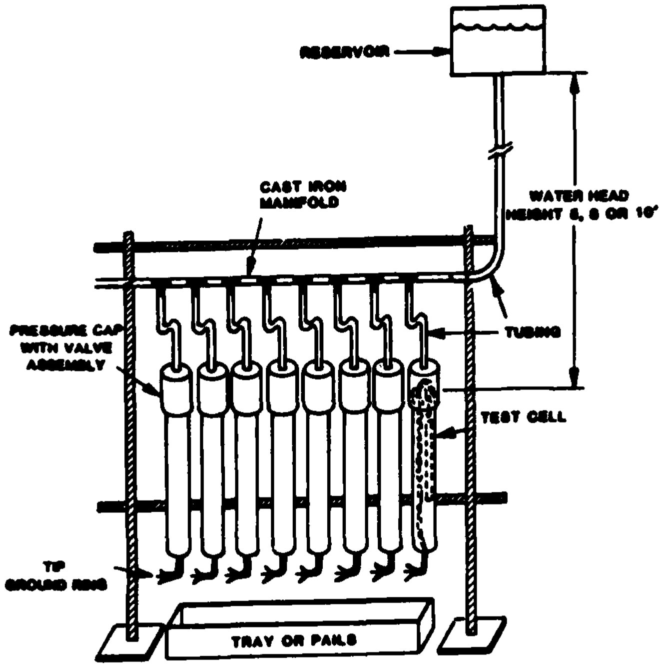


FIGURE 3. BATTERY OF ENCAPSULANT TEST CELLS

In carrying out the test, all tip and all ring conductors are twisted together. Failure was defined as insulation resistance (tip-ring, tip-ground, and ring-ground) readings of $< 10^9$ ohm/cm and/or leakage through the splice. Significantly, water has to travel only one inch along the wire work to reach a splice point and cause failure.

Having designed the splice simulation test, factors which impact on the performance of an encapsulant/closure system were investigated. These factors not only include material properties such as viscosity and gel time but closure considerations such as conductor density as well as external factors such as water head height. The following discussion illustrates selected SST data. These results and other data were used to develop the encapsulant reported in Appendix A.

Effect of Conductor Density

One can readily postulate that as conductor density in a splice increases, encapsulation becomes more difficult. Material properties such as viscosity and gel time can be used to mitigate the problem as discussed below. Similarly, external factors such as encapsulant injection pressure, discussed by Angel et al.[4], can be used advantageously. In order to arrive to the conductor density in the SST design, several experiments were conducted as reported in Table V. The data show a high sensitivity to conductor density. As a result the SST conductor density was standardized to 50 pairs (100 wires, see Appendix B), which is allowed by features in the modular connector used.

TABLE V

SST Results - Effect of Conductor Density

Encapsulant[b]	Height, Ft	Conductor	Number of Conductor Pairs	Days to Failure
F-1	8	FG[a]	5	70+[c]
F-1	8	FG	25	62
F-1	8	FG	50	22

[a]FLEXGEL coated.

[b]Experimental formulations.

[c]Test terminated before failure occurred.

Effect of Water Head

The ideal closure is one which can withstand any water head. Such a goal is not cost effective. SST data presented in Table VI show a strong dependence on water head. As a result, the standard SST water head is 10 feet (see Appendix B).

The enhanced performance of D1000 over D encapsulant is apparent. Significantly, the use of aircore conductors show only a slight improvement and suggest that benefits derived from solvent cleaning of conductors prior to encapsulation will be similarly slight.

TABLE VI

SST Results - Effect of Water Head

Encapsulant	Conductor	Water Head, Ft. 5	8	10
		Days to Failure		
D	FG[a]	2	--	--
D	AC[b]	180+[c]	4	--
F[d]	FG	42	4	--
F-1[d]	FG	121	22	--
N-6XL[d]	FG	59	14	--
D-1[d]	FG	--	303	6
D1000	FG	--	325+	282+

[a]FLEXGEL coated.

[b]Aircore cable.

[c]Test terminated before failure occurred.

[d]Experimental formulations.

Effect of Connector

As indicated in the introduction, filled connectors have been used in the filled cable applications. The experimental data presented in Table VII show no clear advantage of filled over aircore connectors. As a result, the standard SST connector is an aircore modular connector (see Appendix B).

TABLE VII

SST Results - Effect of Connector Type

Encapsulant	Conductor[a]	Water Head, Ft	Modular Aircore Connector	Modular Filled Connector
			Days to Failure	
D	FG	5	2	3
D	AC	8	180+[b]	149+
F-17B[c]	FG	8	151+	151+

[a]FG - FLEXGEL coated, AC - Aircore.

[b]Test terminated before failure occurred.

[c]Experimental formulation.

Effect of Encapsulant Gel Time

Penetration of an encapsulant is strongly dependent on the conductor density of the splice. The encapsulant gel time is normally considered by the user as the time available for the encapsulant to penetrate the splice. The data in Table VIII show that an improvement in performance is possible by increasing the gel time but that more significant improvements can be realized by proper formulation of the encapsulant. This follows because the pot life of the encapsulant is not the gel time but a fraction of it. For example, the pot life could be the time the encapsulant viscosity after mixing increases to 3000 cps. The assumption being that at higher viscosities the degree of penetration in the splice area is significantly reduced. Among other factors which are important is the viscosity-time profile as the encapsulant gels.

TABLE VIII

SST Results - Effect of Catalysis

Encapsulant	Water Head, Ft	Conductors	30-60 Min. Gel Time	17 Hours Gel Time
			Days to Failure	
D	5	FG[a]	2	6
F[b]	8	FG	4	143
F-1[b]	8	FG	22	190+[c]

[a]FLEXGEL coated.

[b]Experimental formulation.

[c]Test terminated before failure occurred.

Effects of Encapsulant Viscosity

The viscosity of an encapsulant is dependent on its composition. Composition can have a strong influence on performance. To separate the effect of viscosity and composition, an experiment was designed in which the encapsulant was mixed and held until the viscosity increased to a specified level and then poured. By partially precuring the encapsulant, the pot life is significantly reduced. This corresponds to the performance of an encapsulant packaged in a dark container and left in the noonday sun prior to mixing. SST results are reported in Table IX. The implications are clear to the formulator and to the user. The viscosity must be controlled to insure a satisfactory pot life at temperatures encountered in the field. Improper use can defeat the best formulation.

TABLE IX

SST Results - Effect of Encapsulant Viscosity

Encapsulant[a]	Water Head, Ft	Conductor	Viscosity, cps ~1000	Viscosity, cps ~4000
			Days to Failure	
F[c]	5	FG[b]	40	3
F-1[c]	5	FG	121	1

[a]Formulas gel in approximately 30-60 min.

[b]FLEXGEL coated.

[c]Experimental formulation.

Effect of Filling Compounds

Telecommunication filled cable suppliers use a multitude of filling compounds - primarily oils gelled with microcrystalline waxes (petrolatum) or styrene block copolymers (FLEXGEL) in combination with polyolefins and variations thereof. The development of an encapsulant compatible with this variety of filling compounds constituted the biggest challenge in this development as shown by SST data in Table X. The performance of the D1000 encapsulant after 200+ days under a 10 foot head of water is not sensitive to whether the conductor is aircore or petrolatum or FLEXGEL coated. These results are a significant improvement over D encapsulant.

TABLE X

SST Results - Effect of Cable Filling Compound

Encapsulant	Water Head, Ft	Days to Failure		
		PJ[a]	FG[b]	AC[c]
D	5	<<1	2	180+[d]
F[e]	5	<<1	42	--
F-1[e]	8	<<1	22	190+
D1000	10	228+	282+	303+

[a]Petrolatum coated conductors.

[b]FLEXGEL coated conductors.

[c]Aircore conductors.

[d]Test terminated before failure occured.

[e]Experimental formulations.

Conclusion

Encapsulated splice closures are widely used to protect a splice from water entry. Failure modes have been briefly reviewed. Assuming water entry down the cable core, closure failures due to oily interphases and wedging have been identified as being strongly encapsulant dependent. A splice simulation test has been developed which assumes that a water head acts directly on the splice. In this worst case situation, variables such as cable filling compounds, splice wire work density, connectors, water head, and encapsulant gel time and viscosity have been investigated. Data have been presented on how these factors influence performance. The result is that a new encapsulant has been formulated which exhibits significant improvements in performance over other commercial encapsulants.

Acknowledgement

The authors wish to express sincere appreciation to their colleagues at AT&T Bell Laboratories and AT&T Technologies for their support and help. In particular, we wish to express our thanks to D. M. Mitchell and D. W. Lemke for their help in devising and carrying out the splice simulation test.

References

1. Dean, N. S., "The Development of Fully Filled Cables for the Telephone Distribution Network," Seventeenth International Wire and Cable Symposium, Proceedings, December 1968.

2. Biskeborn, M. C., and Dobbin, D. P., "Waterproof Plastic Insulated Multipair Telephone Cable," Seventeenth International Wire and Cable Symposium, Proceedings, December, 1968.

3. Brauer, M., and Sabia, R., "Design Considerations, Chemistry and Performance of a Reenterable Polyurethane Encapsulant," Twenty-Fourth International Wire and Cable Symposium, Proceedings, 1975.

4. Angel, C. E., Mullin, F. J. and Reed, W. C., "A Forced Encapsulation System for Splice Closures," Paper to be presented at the Thirty-Fourth International Wire and Cable Symposium, Cherry Hill, New Jersey, 1985.

5. Bellcore CA08735 D Encapsulant Specification, Issue 1.

6. Bell System Technical Reference, PUB 55004, Issue 1., "Waterproof Splice Closures" 1981.

7. Mitchell, D. M., and Sabia, R., "Development, Characterization, and Performance of an Improved Cable Filling Compound," Twenty-Ninth International Wire and Cable Symposium, Proceedings, 1980.

8. McCann, J. P., Sabia, R., and Wargotz, B., "Characterization of Filler and Insulation in Waterproof Cable," Eighteenth Wire and Cable Symposium, Proceedings, 1969.

ATTACHMENT A

D1000 Encapsulant Test Results
Based on Bellcore CA08735 Encapsulant Specification

CHEMICAL REQUIREMENTS:

Chemical Property	Requirement	D1000 Encapsulant Results
1. Isocyanate Content	6.5 - 8% NCO	* 7.3%

PHYSICAL REQUIREMENTS:

Physical Property	Requirement	D1000 Encapsulant Results
1. Corrosion of Copper	Noncorrosive to copper	* Noncorrosive, no visual change observed * 1.04 x 10^{10} ohms after 4 hours
2. Hydrolytic Stability	Specimen shall not disintegrate, noticeably swell, or revert to a liquid. The weight shall not change by -10%, +5%	* 0.85% loss * no visual changes * tack free
3. Peak exotherm	120°F	* 10°F rise from 75°F
4. Water Absorption	Weight increase after 7 days in 75 ± 2°F distilled water. Average of two specimens, shall be 0.8% maximum	* 0.05%
5. Dry Heat Aging & Weight Loss	Specimens shall not char or revert to a liquid 4% maximum loss at 212°F.	* 1.50% gain
6. Fungi Resistance	"0" rating: No growth permitted	* No growth observed
7. Gel Time[1]	25 ± 10 minutes at 75°F, 110 ± 15 minutes at 40°F	* 55 ± 10 minutes at 75°F * 150 ± 15 minutes at 40°F
8. Volumetric Expansion	Change not to exceed +2%	* No change (<0.2% observed)
9. Stress Cracking of Polyethylene	Only 2 specimens can fail	* No failures observed
10. Viscosity,[1] cps		
a) prepolymer:	1500 max. at 40°F	* 6,100 cps (0.3 rpm, #18 spindle @ 38°F)
b) polyol:	1500 max. at 40°F	* 3,900 cps (0.3 rpm, #18 spindle @ 38°F)
11. Tensile Strength	6-30 psi	* 27.3 psi
12. Elongation	50% min. 250% max.	* 92%
13. Tear Strength		
a) at 25°C	6.0 lbs/in max. 3.0 lbs/in min.	* 4.2 lbs/in
b) at -18°C	10.0 lbs/in max.	* 9.0 lbs/in
c) after dry heat aging, at 25°C	6.0 lbs/in max. 3.0 lbs/in min.	* 2.4 lbs/in
14. Stress Cracking of Polycarbonate	No stress cracking by mixed material during or subsequent to cure	* No effect

[1]As indicated in the text, an increase in value was necessary to attain improved closure performance.

[2]See CA08735 Specification.

Physical Requirements cont'd:

Physical Property	Requirement	D1000 Encapsulant Results
15. Water Sensitivity	Change not to exceed, 2%	* No shrinkage or expansion observed
16. Pour point		
a) prepolymer:	-5°F max.	* <-5°F
b) polyol	-5°F max.	* -27°F
17. Compatibility	See Par. 6.09[2]	* Compatible, good adhesion
18. Shelf life	See Par. 6.10[2]	* After 12 weeks at 60°C the components and mix viscosities as well as the gel time did change significantly. It is assumed that all other properties also did not change significantly.
19. Colors	See Par. 6.11[2]	* Clear solution when mixed
20. Bond to liner	See Par. 6.12[2]	* 100% adhesion
21. ond to DR tape	See Par. 6.13[2]	* 100% adhesion
22. dor	Essentially odorless	* Essentially odorless
23. Phase stability	See Par. 6.15[2]	* No striations, clear
24. Coated Conductor Pull-Out Test		
a) Flexgel	Min. 0.5 kg	* 5.1 kg
b) petrolatum	Min. 0.5 kg	* 1.8 kg
25. Liquid Compatibility	See Par. 6.17[2]	* Complete bonding, no adverse *effects observed*

ELECTRICAL DATA:

Electrical Property	Requirement	D1000 Encapsulant Results
1. Insulation Resistance		
mixed, cured encapsulant	1 x 10^{10} ohms minimum after 28 days	* 3.5 x 10^{10} ohms

ATTACHMENT B

Assembly and Encapsulation Procedure

Note - Refer to Figure 2 for reference.

1. Remove a 25 pair unit from the test cable and remove binder ties.

2. Splice 50 conductors to the 25 pair modular connector so that 25 pairs exit on the index strip side and 25 pairs exit on the cap side. Adhere to the color code. The bridge module is not used in this test.

3. Dress the conductors to one end of the connector as is done in normal practice. Two inches after the end of the connector, bend the 25 pair units back over themselves forming a two inch loop.

4. Place a bare copper ground wire along the conductors with the end 2 inches longer than the end of the loop.

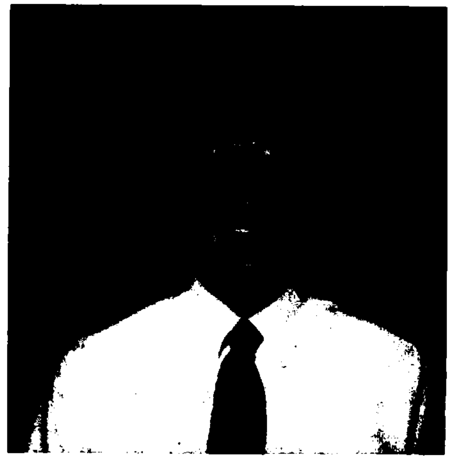
5. Wrap the liner around the splice with the 2 inch loop of conductors and 4 inch ground wire projecting out of one end. The loop end of the modular connector should be 0.5 inches inside the end of the liner. Secure the liner with the three cable ties; one at each end and one in the middle.

6. Insert the wrapped splice into 2 inch I.D. Plexiglas tube (14 inches long), and position the loop end of the liner 0.5 inches from the end of the tube. At this position, the loop end of the modular connector should be 1 inch inside the top of the tube.

7. Identify one of the two 25 pair units extending out of the tube. Cut it off 3-4 inches from the end of the tube and secure the conductors with a cable tie. Make sure that when the end is cut the conductor ends are "cleared", that is, there are no contacts between conductors. On the remaining unit, separate and strip the tip and ring conductors and twist the stripped ends together. Secure the ground wire and conductors with two cable ties.

8. A seal is made in the bottom of the tube (with encapsulant), and after it has cured, the tube is filled with encapsulant with the tube positioned vertically.

9. After the encapsulant has cured, a pressure cap with valve assembly is attached to the tube and attached to the manifold for testing (see Figure 3).



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